PB81-244352

Community Noise Assessment Manual
Strategy Guidelines for Developing a
Community Noise Control Program

Wyle Research
El Segundo, CA

Prepared for

Environmental Protection Agency
Washington, DC

Jul 81

U.S. Department of Commerce
National Technical Information Service
NTIS

PB81-244352

COMMUNITY NOISE ASSESSMENT MANUAL

STRATEGY GUIDELINES FOR DEVELOPING A COMMUNITY NOISE CONTROL PROGRAM

July 1981

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Noise Abatement and Control
Washington, D.C. 20460

Under Contract No. 68-01-3921

This report has been approved for general availability. The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein. This report does not necessarily reflect the official views or policy of EPA. This report does not constitute a standard, specification, or regulation.

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

NOTICE

THIS DOCUMENT HAS BEEN REPRODUCED FROM THE BEST COPY FURNISHED US BY THE SPONSORING AGENCY. ALTHOUGH IT IS RECOGNIZED THAT CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED IN THE INTEREST OF MAKING AVAILABLE AS MUCH INFORMATION AS POSSIBLE.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Strategy Guidelines for Developing a Community Noise Control Program		5. REPORT DATE July 1981 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Wyle Research, El Segundo, CA 90245		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-01-3921
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency 401 M. St. S.W. Washington, D.C. 20460		13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE 200/02

15. SUPPLEMENTARY NOTES

Reproduced from best available copy.

16. ABSTRACT

This report was prepared by EPA, Office of Noise Abatement and Control, in support of its function to provide technical assistance to communities. It is one of nine which comprises the Community Noise Assessment Manual. The Manual provides a comprehensive and computerized system for assessing the noise problems of a community and then planning a noise control strategy for its abatement. This report assists communities in determining, in an objective manner, the efficient allocation of funds for reducing the adverse effects of noise in their community. Since the number of possible combinations of noise sources and corresponding countermeasures to reduce their impact can be quite large, a computer-based approach is therefore used to develop optimum scenarios for noise control expenditures. This Manual utilizes an optimization computer model, which selects the most cost-effective noise abatement measures and the amount of money which should be spent on each. The primary criterion for optimization is based on economic and acoustical data gathered in the community.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT Release to the public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 221
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

WYLE LABORATORIES

WYLE RESEARCH REPORT

WR 78-1

COMMUNITY NOISE ASSESSMENT MANUAL

STRATEGY GUIDELINES

For

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Noise Abatement and Control
Arlington, Virginia 22202
(Contract No. 68-01-3921)

By

WYLE RESEARCH
El Segundo, California 90245

AUGUST 1979

REPORT

FOREWORD

In response to Congressional mandates, the U. S. Environmental Protection Agency, Office of Noise Abatement and Control, has funded the development of a series of manuals, prepared by Wyle Laboratories, to support a Quiet Cities Program. The first of these manuals, entitled "Community Noise Assessment Manual - Social Survey Workbook,"[1*] provided detailed instructions for conducting an attitudinal survey on noise in a community. The second manual, entitled "Community Noise Assessment Manual - Acoustical Survey,"[2] provided detailed practical procedures for conducting a noise measurement survey in a community. This manual, the third in this series, is designed to assist local governments in making logical and cost-effective decisions on the allocation of funds to reduce the adverse effects of noise in their communities. To make maximum use of the material in this document, a community will have utilized the preceding manuals, or their equivalents, to obtain detailed data on the noise environment, and attitudes toward this environment, in their community. However, this manual also stands alone in that it contains many useful guidelines and procedures which a community can utilize to decide on the most efficient allocation of effort and funds directed toward preserving the natural resource - quiet - in their community.

---

*See References for a complete citation.

TABLE OF CONTENTS

Page

1.0 INTRODUCTION 1-1

1.1 Purpose of the Manual 1-1
1.2 Description of the Optimization Model (Noizop) 1-4
1.3 Noise Impact of Specific Sources 1-8
1.4 How to Use the Manual 1-10

2.0 IDENTIFICATION OF NOISE PROBLEMS 2-1

2.1 Develop a Source/Location Impact Matrix 2-2
2.2 Collect Complaint Information 2-10
2.3 Collect Attitudinal Information 2-11
2.4 Collect Acoustical Information 2-14
2.5 Select Problem Areas to Investigate 2-21

3.0 QUANTIFY ALTERNATIVES 3-1

3.1 Identify Appropriate Alternatives 3-1
3.2 Select Year to Apply Optimization Model 3-2
3.3 Prepare Community Data 3-17

3.3.1 Divide Community Into Cells 3-17
3.3.2 Estimate Cell Populations 3-19
3.3.3 Establish Baseline Noise Levels 3-31
3.3.4 Apply "Attitude Adjustment Factors" to Baseline Noise Levels for Each Source 3-31
3.3.5 Prepare Land Use Information 3-38

3.4 Estimate Costs and Noise Reductions of Alternatives . . . 3-39

3.4.1 Noise Standard (Operational) 3-50
3.4.2 Operational Controls 3-56
3.4.3 Area Restrictions 3-64
3.4.4 Time Restrictions 3-66

TABLE OF CONTENTS (Continued)

3.4.5 Permits 3-69

3.4.6 Barriers 3-70

3.4.7 Building Insulation 3-74

3.4.8 Compensation 3-77

3.4.9 Population Relocation 3-79

3.4.10 Planning/Zoning 3-81

3.4.11 Building Codes 3-84

3.4.12 Tax Incentives 3-87

3.4.13 Tax Penalty 3-92

3.4.14 Noise Standard 3-95

3.4.15 Labeling 3-97

3.4.16 Maintenance Standard 3-100

3.4.17 Retrofit Standard 3-103

3.4.18 Education 3-103

3.4.19 Complaint Mechanism 3-107

4.0 SELECTION OF OPTIMAL ACTIONS 4-1

4.1 Operate Noizop Program 4-1

4.1.1 Assemble Input Data 4-1

4.1.2 Obtain Output Results 4-1

4.2 Evaluate Output Results 4-8

4.3 Select Final Set of Noise Abatement Measures 4-10

REFERENCES R-1,2,3

APPENDIX A NOISE ABATEMENT OPTIMIZATION PROGRAM

A.1 Introduction A-1

A.2 Updates to the User's Guide and Programmer's Guide A-2

  A.2.1 User's Guide Update A-2

  A.2.2 Programmer's Guide Updates A-11

A.3 Quantification of Model for Six Sets of Hypothetical Applications A-12

A.4 Summary of the Allentown Strategy Analysis A-30

APPENDIX B VEHICLE STATISTICS COMPUTER PROGRAM (VESTA)

B.1 Basic Concepts B-1

B.2 Input Data B-4

B.3 VESTA Tax Measures and New Product Regulations B-6

B.4 VESTA Program Listing B-11

√

LIST OF TABLES

Table		Page
1-1	A-Weighted Equivalent Sound Levels Assumed in this Manual for Zero Impact (NII = 0) and 100 Percent Impact (NII = 1.0), by Land Use	1-7
2-1	List of Noise Zones Used in the Attitudinal and Acoustical Surveys	2-6
2-2	Categories of Community Noise Sources Considered in this Manual	2-7
2-3	Example Tabulation of Complaints Showing Percent of Households in Each Noise Zone Complaining, by Source of Complaints	2-12
2-4	Example Tabulation of Surveyed Attitudes Showing Percent of Households in Each Noise Zone Significantly Annoyed by Each Noise Source	2-15
2-5	Comparison of Noise Sources Used in EPA Acoustical Survey Manual with Those Used in this Manual	2-18
2-6	Estimated Noise Levels for Noise Zones with No Source-Specific Data	2-19
2-7	Example Tabulation of Noise Levels (L_{dn}) Showing Contribution of Sources in Each Noise Zone	2-22
2-8	Example Impact Matrix Showing Source and Location (Noise Zone) of "Excessive Impacts" Identified from Tables 2-3, 2-4 and 2-7	2-23
3-1	List of Abatement Alternatives Which Local Governments May Apply to Community Noise Sources	3-2
3-2	Countermeasures Which Local Governments Can Apply to Community Noise Sources	3-4
3-3	Identification of Specific Measures for Treating Problem Noise Sources	3-7
3-4(a)	Worksheet for Identifying Community Attitudes Toward Abatement Alternatives	3-10
3-4(b)	Worksheet for Identifying Community Attitudes Toward Abatement Alternatives	3-11

LIST OF TABLES (Continued)

Table		Page
3-5	Example Selection of Short-Term or Long-Term Analysis Year	3-16
3-6	Land Use Codes to be Used for Each Cell	3-38
3-7	Meaning and Symbols of Countermeasure Cost Components	3-42
3-8	Cost Components of Each Alternative	3-43
3-9	Default Cost Values for Selected Cost Components	3-44
3-10	Factors for Calculating Present Value of Costs Based on a 10 Percent Discount Rate	3-46
3-11	Default Values in dB to be Used in Estimating Present Noise Levels of Selected Sources	3-53
3-12	Cost of Delays in Construction Schedule (C_S)	3-58
3-13	Cost of Barriers	3-70
3-14	Barrier Effectiveness Ratios for Low and High Barriers, by Noise Source	3-73
3-15	Fuel Savings	3-76
3-16	Incremental Noise Reduction Achieved with Selected Levels of Insulation Applied to Existing Homes	3-76
3-17	Annualized Property Value Reduction (V_R) in 1977 Dollars Due to Selected Increases in Noise Level	3-79
3-18	Estimated Increase in Noise Reduction Achieved by Modifying New Construction Practices with Selected Degrees of Building Codes by Cost to Conform	3-86
4-1	Summary of Input Data Required by Noizop	4-2
4-2	Extent of Countermeasure Application to the Six Hypothetical Examples	4-13

LIST OF FIGURES

Figure		Page
1-1	Basic Sequence of Procedures Followed in this Manual	1-2
1-2	Source Noise and Annoyance Characteristics from Allentown Study	1-9
2-1	Nomogram for Determining (a) Complaint, (b) Attitude, and (c) Noise Level Criteria to Identify Noise Problems	2-3
2-2	Assembly of Complaint, Attitudinal, and Acoustical Data in Source/Location Impact Matrices	2-5
2-3	Question 17 from the EPA Attitudinal Survey to Determine How Annoyed People Are by Various Noise Sources	2-13
2-4	Example Output of Computerized Reduction of Acoustical Survey Data Illustrating Component Source Levels	2-17
3-1	Annual Noise Reduction Benefits and Discounted Annual Costs: An Illustration of the Change in Cost-Effectiveness Due to Timing of Expenditures	3-15
3-2	Illustrative Example of Community Noise Zones Divided Into Cells	3-18
3-3	Index to Census Map Sheets for the Washington, D.C.-Md.-Va. Urbanized Area	3-21
3-4	Section of Alexandria, Virginia Showing Computation of Approximate Area of a Typical Census Tract	3-22
3-5	Excerpt from U.S. Bureau of the Census 1970 Block Statistics for Alexandria, Virginia Showing Total Population of a Sample Tract	3-23
3-6	Estimation of Individual Cell Populations in Each Type of Noise Zone	3-26
3-7	Hypothetical Plot of Acoustical and Attitudinal Data for Calculation of Attitudinal Adjustment Factors	3-33
3-8	Example Flow of Computer Output for Calculating Attitudinal Adjustment Factors	3-34
3-9	Example Computer Output Presenting the Final Attitudinal Adjustment Factors	3-37

LIST OF FIGURES (Continued)

Figure		Page
3-10	Illustrative Example of Redistribution of a Source Population to Comply with a Regulation	3-55
3-11	Three Possible Incentive Schemes to Bring Product Noise Levels Below a Criterion Level	3-88
3-12(a)	Redistribution of New Product Noise Levels Below a Cut-Off Due to an Incentive Proportional to Additional Costs Incurred	3-91
3-12(b)	Redistribution of New Product Noise Levels Below a Cut-Off Due to a Penalty Proportional to Additional Costs Incurred Plus dB Above Cut-Off	3-91
3-13	Three Possible Penalty Schemes to Bring Product Noise Levels Below a Criterion Level	3-94
3-14	Items of Information Needed to Use the VESTA Computer Program	3-102
4-1	Example Noizop Output During Optimization Process	4-6
4-2	Example Noizop Output Illustrating Optimization of the User Budget Level of Expenditures	4-7
4-3	Example Results Page of Noizop Output	4-9
4-4	Baseline Case Optimization Results	4-11

1.0 INTRODUCTION

1.1 Purpose of the Manual

In response to EPA's mandate to actively support the development of quiet communities, this manual has been developed to assist local governments in determining, in an objective manner, the efficient allocation of funds for reducing the adverse effects of noise in their communities. Since the number of possible combinations of noise sources and corresponding countermeasures to reduce their impact can be quite large, a computer-based approach is therefore called for to develop optimum scenarios for expenditures. The procedure described in this manual utilizes an optimization computer model called "Noizop" which selects the most cost-effective noise abatement measures and the amount of money which should be spent on each.[3] The primary criterion for optimization is based on economic and acoustical data gathered in the community. While the procedures involved in obtaining cost estimates for the noise countermeasures and noise level data for the community noise sources to be abated are somewhat involved, the overall approach is conceptually quite simple and, even without use of a computer, much of the material will provide very useful guidelines for devising noise control strategies of any desired detail.

The approach consists of the three basic steps illustrated in Figure 1-1:

Step 1. Find out what the problems are. (Chapter 2)

- What noises are people complaining about?
- What noises are people annoyed by?
- How loud are the noise sources?
- Which noise sources should be considered as problems, and therefore as candidates for noise reduction?

Step 2. Find out what the solutions are. (Chapter 3)

- What solutions are appropriate for the identified problems?
- How much do they cost?
- How effective are they?
- Are they politically and socially feasible?

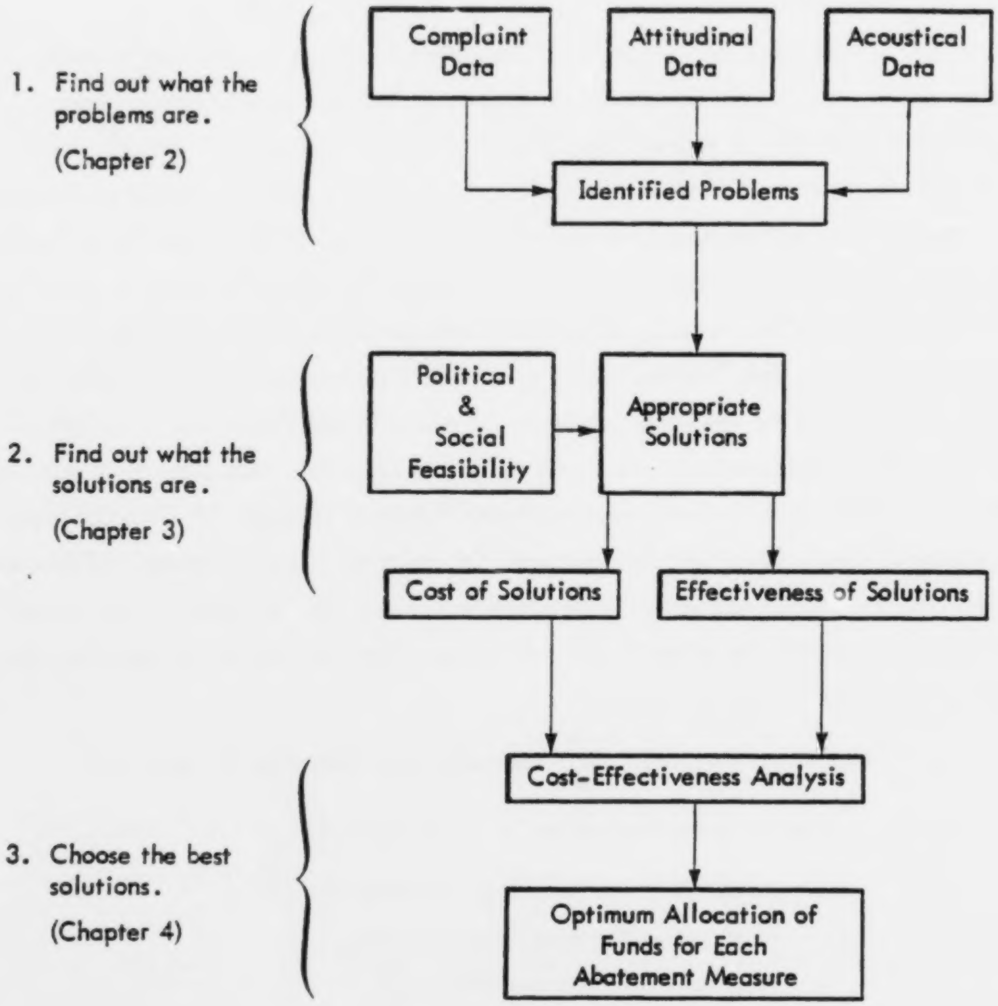

1. Find out what the problems are.
(Chapter 2)
Complaint Data
Attitudinal Data
Acoustical Data
Identified Problems
2. Find out what the solutions are.
(Chapter 3)
Political & Social Feasibility
Appropriate Solutions
Cost of Solutions
Effectiveness of Solutions
3. Choose the best solutions.
(Chapter 4)
Cost-Effectiveness Analysis
Optimum Allocation of Funds for Each Abatement Measure

Figure 1-1. Basic Sequence of Procedures Followed in this Manual

Step 3. Choose the best solutions. (Chapter 4)

- How much money should be spent on each alternative solution to achieve the maximum benefit, and still remain within the budget?

Three approaches are available for Step 1 to "find out what the problems are."

1. A survey of peoples' attitudes toward noise may be conducted using a standard survey procedure developed by EPA.[1] The attitudinal survey provides information on the number of people who are annoyed (and to what degree) by various sources of noise in different areas of the community, what types of noise abatement solutions they support, and how much they are willing to pay for noise abatement. Thus, the extent of community annoyance from various noise sources is used in this manual as one criterion for identifying specific community noise problems.
2. An EPA-designed acoustical survey[2] may be conducted to provide the actual noise levels produced by the various noise sources in the community and thus provide a second criterion which can be used to identify noise problems.
3. The third method for identifying problem sources can be based on the number of complaints issued by the community residents concerning the various sources of noise.

While it is not absolutely necessary that the EPA attitudinal and acoustical surveys be performed before the procedures in this manual are followed, it is necessary that the user of this manual be knowledgeable of the residents' attitudes toward the community noise sources and the physical noise levels produced by these sources so that candidates for noise abatement treatment can be identified. The language in this manual frequently refers to results of the attitudinal and acoustical surveys.

To "find out what the solutions are" (Step 2), a series of procedures are described in this manual which will assist the reader to (1) identify the most promising solutions to the problems identified in Step 1, (2) estimate the costs of implementing each solution; and (3) estimate the noise level reductions obtained as a result of implementing each solution. Abatement measures which are found to be infeasible from the political or social acceptability or practicability standpoint are eliminated from consideration, while additional measures which the community specifically wishes to support are added to the list of solutions to be analyzed.

Finally, to "choose the best solutions" (Step 3), the computer-based cost-effectiveness analysis is carried out. The resulting recommendations are then evaluated and, if necessary, modified. A final set of abatement measures and associated levels of expenditure are then selected and implemented. While this manual does not describe how to actually implement each individual noise control measure (for instance, there are no guidelines provided on how to set up a vehicle maintenance program), methods are given for determining the essential goals of each noise abatement measure.

It is assumed that a computer is available to the user to run the cost-effectiveness optimization computer model.[3] Even if this is not the case, however, most of Chapter 2 and Sections 3.1 and 3.4 of Chapter 3 of this manual will still be of value to users interested in identifying community noise problems and in determining the costs and effectiveness of the most appropriate solutions.

1.2 Description of the Optimization Model (Noizop)

The ultimate purpose of Noizop is to provide a tool for rational and objective decision making in policy and regulatory activity concerning environmental acoustic noise from all sources. Simply stated, the problem is to distribute a given hypothetical sum of money in such a way as to obtain the greatest possible benefit in terms of reduction of the number of people adversely affected by environmental noise. This is a problem of operations research, and it requires an involved computer program to properly handle the task. The inherent nonlinearity of the mathematics that describe the problem prevent the use of well developed methods of linear algebra. A sophisticated searching algorithm is utilized in the program to find the most cost-effective way of distributing the given sum of money among the alternative noise abatement measures.

For purposes of a mathematical formulation of the problem, a quantity is defined that rates the quality of the environmental noise climate of a community. This quantity is called the Noise Impact Index, abbreviated to NII:

$$\text{NII} = \frac{\text{Number of People in a Given Community Impacted by Noise}}{\text{Total Number of People in the Community}}$$

The noise climate quality improves with declining NII. In operations research language, the NII is the objective function (i.e., it is the single function to be minimized by the judicious distribution of the given sum of money).

In using the optimization model, the community is divided into homogeneous noise zones, and these zones are further divided into cells. While the population and land use of each cell in a zone may be different, the noise levels to which the cell is exposed from various sources are assumed to be uniformly represented by the average noise levels in the noise zone which are measured in the acoustical survey.

The basic repetitive task performed by Noizop is to apply, at each cell, the selected means or countermeasures for reducing noise impact for a specified distribution of expenditures, noting the number of people no longer impacted by noise, and computing a new (reduced) NII. This task is performed a large number of times during any one execution of Noizop as it searches for the distribution of expenditures which gives the greatest NII reduction for a given budget. The effect of an abatement measure in the community is modeled by estimating the change in impact (quantified by the Noise Impact Index) which occurs for the population in each of the cells when the cell noise levels are reduced as a result of hypothetically applying that noise abatement measure.

In choosing the best set of abatement measures, Noizop spends money in incremental amounts until a preset maximum is reached. At each step, money is spent on the abatement measure with the best cost-effectiveness ratio. A portion of the money spent may be incurred by the local government. This cost to the local government and the total primary cost (see Section 3.4) to all segments of society are displayed by the computer program at each step of the optimization process so that for any desired local government budget, the most cost-effective community expenditure can be determined. Noizop selects alternatives based on total societal costs of each countermeasure — not those measures which are least costly from the local government's point of view. This approach is appropriate since the benefits of abatement measures are also measured in terms of the effects on the community as a whole.

The value of the NII in a particular cell is proportional to the product of a weighting function, which depends upon the noise level found in that cell, and the cell population. A different weighting function is also used for day and night. The noise level at which the noise impact is defined to be zero is shown in Table 1-1. Note that for each land use, the noise level where 100 percent impact is assumed to occur is 20 dB higher than the zero impact level.[4] The NII weighting function* at intermediate levels is assumed to vary linearly between the zero and 100 percent impact points. For example, the NII weighting function for a cell in the community where the noise level is 10 dB above the zero impact level is equal to 0.5. Similarly, the weighting for an area where the noise level is 30 dB above the zero impact level is equal to 1.5.

The metric used to define the noise levels in the community is the Equivalent Sound Level, L_{eq}. This level is the energy average of the momentary A-weighted levels measured over a specified period of time. The daytime L_{eq}, symbolized by L_d, is averaged over the hours from 7 a.m. to 10 p.m. The nighttime L_{eq}, symbolized by L_n, is averaged over the hours from 10 p.m. to 7 a.m.

---

*Equivalent to the term "fractional impact" employed by EPA.

Table 1-1

A-Weighted Equivalent Sound Levels Assumed in this Manual for Zero Impact (NII = 0) and 100 Percent Impact (NII = 1.0), by Land Use*

Land Use		Zero Impact		100% Impact	
		Day	Night	Day	Night
R1	Single-Family Dwelling	54	46	74	66
R2	Multi-Family Dwelling	59	46	79	66
C	Commercial	59	59	79	79
I	Industrial	70	70	90	90
S	Schools	55	-	75	-
H	Hospitals	50	50	70	70

Derivation

R1 Chosen to give L_{dn} = 55 dB per EPA "Levels Document"[4] for zero health and welfare effects in residential areas. Assumes that $L_{day} - L_{night}$ = 8 dB which is a reasonable approximation to actual environment (based on 100-site survey in Reference 5) and agrees with the day-night difference cited in Reference 6 (Table 3.2-6) for R1 land use.

R2 Assumes that a typical outdoor-indoor noise reduction for multi-family dwellings during the daytime (windows closed) would be 5 dB greater than for single-family dwellings.

C Assumes that the day and night criterion levels should be the same as for R2 (day).

I Assumes that the zero impact limit should be 20 dB below OSHA requirements of 90 dB for both day and night.

S Per EPA "Levels Document," $L_{eq(24)}$ criteria inside schools, etc., is 45 dB. Assuming a minimum noise reduction of 10 dB with windows open gives a zero impact level of 55 dB. No night criterion needed.

H Assumes the same levels for both day and night which correspond (within 1 dB) to an L_{dn} of 55, consistent with EPA "Levels Document."

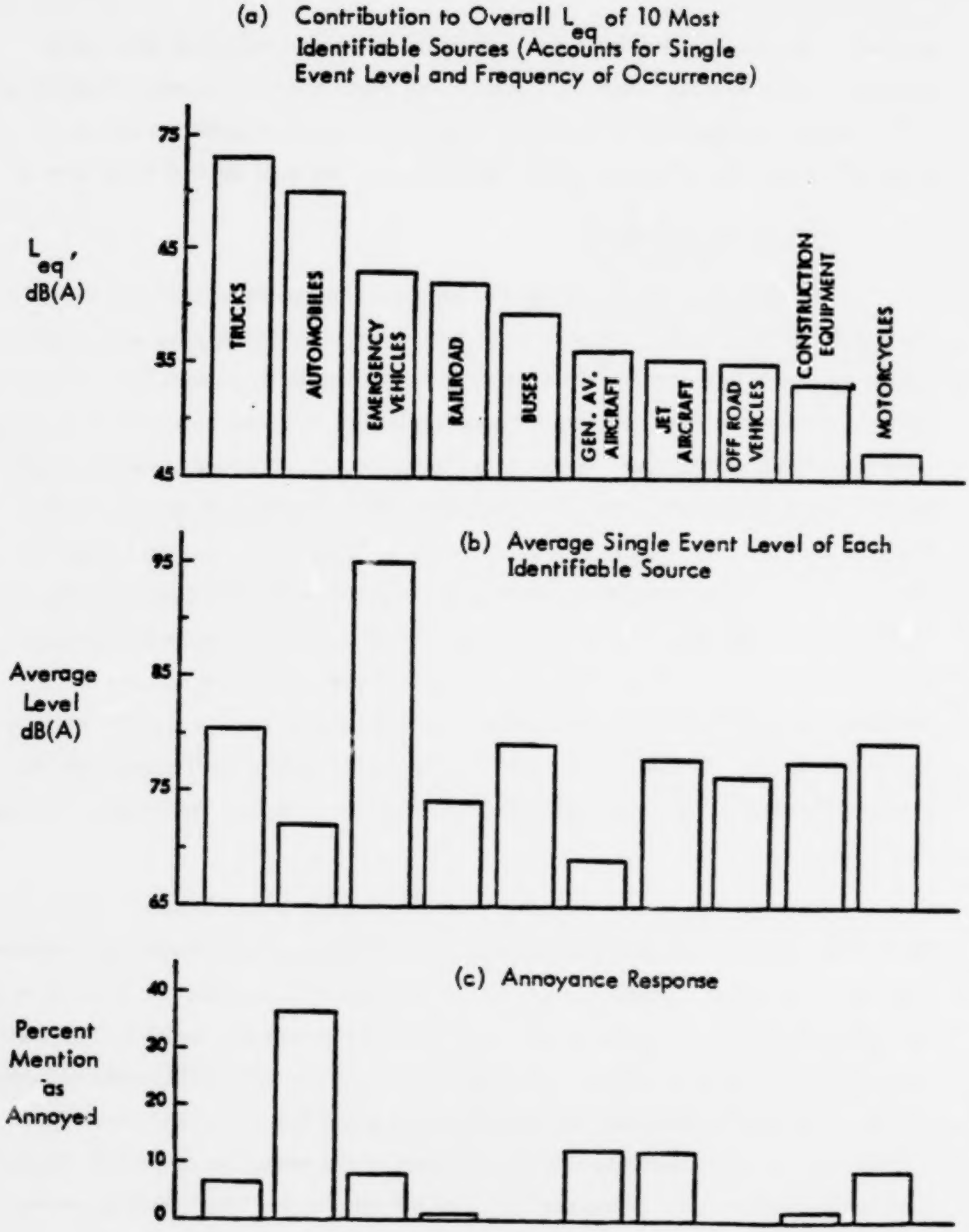
*These criterion values represent best estimates and intentionally have not been rounded to the nearest 5 dB which would ordinarily be done to reflect, more realistically, their accuracy.

An important community-specific aspect to the analysis described in this manual is the ability to "adjust" noise levels of individual sources to account for situations in which the community is much more annoyed or much less annoyed than "average" by a particular source of noise. As a hypothetical example, consider the case in which motorcycles producing noise levels of 70 dB cause 20 percent of the neighboring households to report, in the attitudinal survey, that they are highly annoyed by motorcycle noise, whereas for other sources, a noise level of 75 dB is required to cause this same degree of annoyance. In this case, an adjustment factor of 5 dB is added to the motorcycle noise levels so that the impact of this source is given as much weight by the optimization model as that of a louder but equally annoying noise source. A rigorous procedure for computing adjustment factors for each noise source is described in Section 3.3.3.

1.3 Noise Impact of Specific Sources

As suggested by the preceding paragraph, the contribution of individual sources to the total noise in any given area can be adjusted, to account, in any approximate way, for the relative annoyance which a community expresses toward such specific sources. This will substantially improve the ability to develop an optimum strategy for countermeasures to reduce the total noise impact from all the significant noise sources in a community. This global approach to community noise reduction is a basic objective of this strategy guideline. However, a community may also be faced with noise problems concerned with just one or two specific sources whose physical contribution to the total community noise climate may be small and not necessarily indicative of community annoyance response to the sources. For example, as illustrated in Figure 1-2, from results of a recent EPA-sponsored noise survey in Allentown, Pennsylvania, the top 10 specific sources which contribute the most to community noise levels (Figure 1-2a) do not rank in the same way as the actual noise levels of each source (Figure 1-2b) or as the apparent relative annoyance response to each source (Figure 1-2c).

In such cases, exercising the complete optimization strategy outined in this manual may not be cost-effective for the community to abate such singular noise



problems. Instead, a more direct approach aimed at the particular offending noise source(s) may be in order. However, even in this case, much of the material contained in this manual, particularly in Section 3.1, will be of value in guiding a community to select effective noise abatement action for just one or two well defined noise sources.

1.4 How to Use the Manual

The remaining sections of the manual are organized in accordance with the flowchart of Figure 1-1, shown earlier on page 1-2. First, use data from the acoustical and attitudinal surveys to help identify noise problems in the community as described in Chapter 2. Second, identify potential solutions to these problems as discussed in Section 3.1. After abatement measures have been selected for the optimization analysis, select a "target year" in the future at which the costs and effects of the measures are to be compared (Section 3.2) and prepare data on the community for input to the computer model. (Section 3.3). The target year is that time in the future when the countermeasures will be in full effect. Sections 3.2 and 3.3 may be skipped if the computerized optimization analysis is not desired. Next, estimate the costs of each abatement measure and the associated reductions in noise level for each affected source which are expected to result in the target year. Finally, as described in Chapter 4, operate the Noizop computer program, obtain and evaluate the results, and select the final set of actions recommended for your community.

For assistance in operating the noise optimization program, consult Appendix A. Section A.1 provides an additional introduction to Noizop and references the complete Noizop User's Guide (a separate document).[3] Section A.2 describes the revisions to this User's Guide to reflect the additional capabilities of the computer model incorporated for this manual. In Section A.3, some hypothetical applications of the model of interest to local governments are shown based on data from a previous analysis of Menlo Park, California. An actual example of the application of the manual to Allentown, Pennsylvania is shown in Section A.4. A program listing of the updated version of Noizop (written in FORTRAN IV) is available from EPA.

Appendix B provides a discussion and listing of a Vehicle Statistics Program (VESTA) which is used to estimate the effects of various vehicle noise abatement measures described in this manual.

2.0 IDENTIFICATION OF NOISE PROBLEMS

The identification of noise problems in a community must begin with a definition of the term "noise problem." For purposes of this manual, a noise problem will be said to exist if indicators of the adverse effects of a source of noise on some part of the community become "excessive;" that is, they exceed some predetermined value. Whether or not the effects of a source of noise in some location are actually felt to be excessive may depend a great deal on individual opinions. A newly-recruited truck driver may feel the noise inside his cab is "excessive," while the owner of the truck fleet may consider it normal. While neither party may be concerned with the exterior noise generated by the truck, this would be the concern of local residents. This hypothetical situation can also be applied to an industrial plant, a railroad locomotive, or even a recreational park; but, the lesson is the same: criteria need to be formulated so that noise sources which produce excessive adverse effects can be identified. These criteria do not have to be hard-and-fast rules applicable nationwide. They may be based on experience, an understanding of local community priorities, or just personal judgment. However, to protect against biasing the results, criteria should be established before any data are gathered.

There are three main indicators of noise problems in the community for which criteria must be established: (1) specific complaints about a source of noise; (2) negative attitudes toward a source of noise; and (3) excessively high noise levels produced by a source of noise. The following criteria are recommended for each of these indicators for identifying a noise source which can be considered to be a potential noise problem in the community.

Complaints:	More than 1 percent of the households in an area complain about the source.
Attitudes:	More than 4 percent of the households in an area mention that they are annoyed by the source.

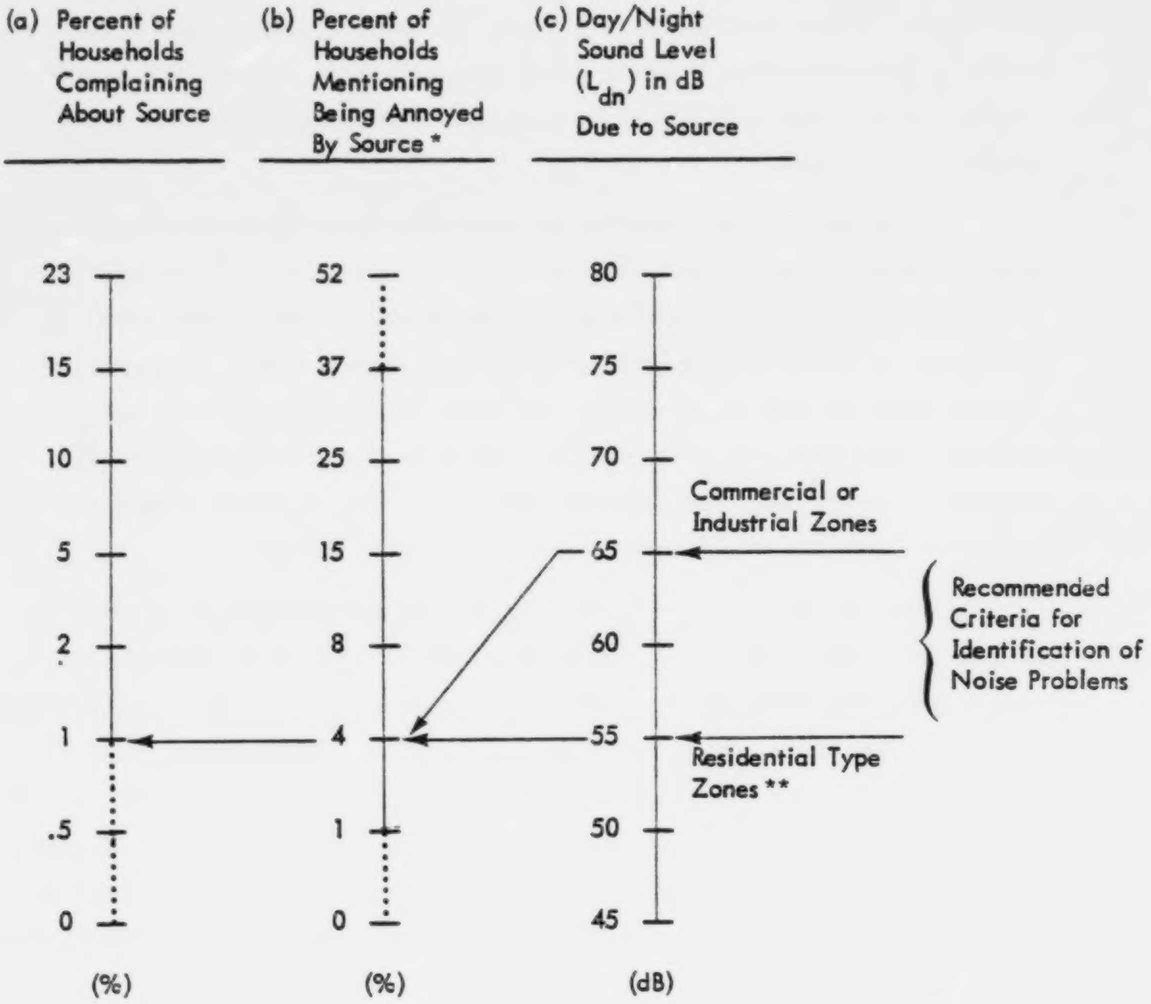
Noise Levels: The day-night sound level (L_{dn}), in an area, due to a specific source, is higher than 55 dB.

Here, an "area" is defined by the concept of a homogeneous noise zone which is described later in this section. Note that these are not environmental noise criteria, but rather they are source-specific noise criteria. If any one of these criteria are exceeded, then, for purposes of this analysis, a noise problem will be assumed to exist. In the final analysis, it may turn out that it is not cost-effective to attempt to eliminate the noise problem. Alternate criteria may be desired, either more or less stringent, if it is found that too many or too few "problem areas" are identified according to these threshold values. Figure 2-1 provides a nomogram for choosing alternate criteria. The recommended criteria have been chosen, however, so that the most disturbing sources of noise and the most affected areas of the community will be identified.

The complaint and noise level criteria are based on the EPA "Levels Document."[4] A noise level of 55 dB is identified as necessary to protect the public health and welfare with an adequate margin of safety. In commercial or industrial zones, this criterion is raised to L_{dn} 65 dB per the rationale in Table 1-1. All other noise zone types are, by the very manner in which they were defined, considered to be predominantly residential in land use. The attitudinal criteria chosen is based on annoyance reaction curves relating L_{dn} with "percent highly annoyed." The relationship used is based on a synthesis of numerous national and international social surveys on noise annoyance.[7] The criterion is based on expected response to an L_{dn} of 55 dB. This criterion is also used in commercial or industrial zones because residents' attitudes toward specific noise sources in these zones are assumed to be the same as for primarily residential zones.

2.1 Develop a Source/Location Impact Matrix

Collect data for each of the three indicators of noise problems mentioned above, showing both the location in the community from which the complaint, attitude, or noise originated and also the noise source with which the complaint, attitude, or noise



*Category "Highly Annoyed or Above" per EPA Attitudinal Survey.

**All zone types except commercial or industrial zones.

Figure 2-1. Nomogram for Determining (a) Complaint, (b) Attitude, and (c) Noise Level Criteria to Identify Noise Problems (based on References 4 and 7; extrapolation shown by dotted line).

is associated. Figure 2-2 illustrates the manner of assembling data for each of the three indicators of noise problems in tabular form. Each table in Figure 2-2 will be called an "impact" matrix. The exact form of the source and location legends of these matrices will now be discussed.

Since data from the attitudinal and acoustical surveys conducted by the community according to methods developed by EPA in previous studies,[1, 2] are assumed to be available for this analysis, locations should be defined in terms of noise zones. A noise zone, as defined in these EPA reports, is a collection of areas in the community which have similar noise characteristics. All areas within a particular noise zone are expected to be affected in a homogeneous manner by similar noise sources, although the areas do not have to be geographically contiguous. The 19 possible noise zones used in the attitudinal and acoustical surveys are listed in Table 2-1.

The noise zones in Table 2-1 are listed in the approximate order in which they are established (see Reference 2). For instance, the airport zones are established first by including all areas of the community which lie within the L_{dn} 65 dB contour (approximately NEF 30) for Airport Zone B and within the L_{dn} 75 dB contour (approximately NEF 40) for Airport Zone A. The railroad zone is then plotted by including all areas of the community dominated by railroad noise, excluding the airport zones. The stationary source noise zones are then established by determining the area over which each stationary source can be heard 50 percent of the time excluding the airport and railroad zones, and so on. Not all noise zones may be defined by the acoustical survey; in fact, a maximum practical limit of 10 different zones is recommended. A map of the noise zones in your community should be available as a result of work performed for the attitudinal and acoustical surveys. Obtain this map and refer to it while reading the following sections of this manual. Noise sources which contribute to the overall noise environment of the noise zones are divided into categories which roughly parallel the zone categories. A list of noise sources arranged by source category is provided in Table 2-2 along with commonly observed examples. Few communities will have noise problems associated with every source. For instance, there may be only one or two stationary sources which warrant investigation, one airport

Complaint Data

Noise Source	Location in the Community			
	A	B	C	Etc.
1	5	–	–	–
2				
3				
Etc.				

Percent of Households in Location A Complaining About Source #1

Attitudinal Data

Noise Source	Location in the Community			
	A	B	C	Etc.
1	4	–	–	–
2				
3				
Etc.				

Percent of Households in Location A Which Mention Being Annoyed by Source #1

Acoustical Data

Noise Source	Location in the Community			
	A	B	C	Etc.
1	59	–	–	–
2				
3				
Etc.				

Day-Night Sound Level (L_{dn}) in dB Contributed by Noise Source #1 in Location A

Figure 2-2. Assembly of Complaint, Attitudinal, and Acoustical Data in Source/Location Impact Matrices

source (if any), perhaps a freight train route and a major highway, a few complaints indicating garbage trucks should be considered, and the usual personal domestic noise problems such as pets and loud stereos.

Table 2-1

List of Noise Zones Used in the Attitudinal and Acoustical Surveys[2]

1. Airport Noise Zone Type A
2. Airport Noise Zone Type B
3. Railroad Noise Zone
4. Stationary Source Noise Zone
5. Commercial Noise Zone
6. Industrial Noise Zone
7. Commercial/Industrial Noise Zone
8. Central Business District
9. Highway Noise Zone
10. Major Roadway Noise Zone Type A
11. Major Roadway Noise Zone Type B
12. Minor Roadway Low Traffic Volume
13. Minor Roadway High Traffic Volume
14. Minor Roadway Noise Zone
15. Residential Low Density
16. Residential Medium Density
17. Residential High Density
18. Residential Very High Density
19. Residential Noise Zone

Table 2-2

Categories of Community Noise Sources
Considered in this Manual

Category	Source	Examples
Stationary	Commercial/Industrial	Power Plant, Railroad Yard, Foundry
	Construction	Highway, Utility, or Building Construction
	Entertainment Center	Race Track, Music Clubs, Outdoor Theater, Bars
Aircraft	Jet	Commercial, Military, Private
	Small Plane	Single-engine Propeller
	Helicopter	Police, Military, Commercial
Rail	Trains	Freight, Passenger, Subway, Streetcar, Monorail
Traffic Vehicle	Traffic	Major & Minor Arterials, Collectors and Boulevards
	Motorcycle	Mo-Ped, Street Cycle, Police Cycle
	Truck	Dump, 18-wheeler, Refrigeration
	Bus	Transit, School, Intercity
	Auto	Sedan, Sports Car, Van, Pickup Truck
	Highway	Freeway, Major High-speed Throughway
Other Vehicle	Service	Garbage Truck, Street Sweeper, Snowplow
	Emergency	Police, Fire, Ambulance, Sirens
Domestic	Pets/Animals	Dogs
	Neighbors' Homes	Stereo Music from within Neighbors' Homes
	Air Conditioners	Air Conditioners, Heat Exchangers and Fans
	Garden Equipment	Lawnmowers, Edgers, Trimmers

At this point, for each noise category, list the principal noise sources in your community.

- Stationary Source – These will already have been identified in the acoustical and attitudinal surveys. Group them in the following categories:
  - Commercial/Industrial Noise Sources
  - Construction Noise Sources
  - Entertainment Center Noise Sources

- Aircraft – For each of the airports which have flight paths over or near your community, determine which of the following aircraft types are represented:
  - Commercial Jet, Military Jet, or Small Private Jet
  - General Aviation (propeller aircraft)
  - Police, Military, or Commercial Helicopters

- Rail – For each main rail line through your community, determine which of the following types of rail vehicles are represented and note whether they are diesel or electric powered:
  - Freight or Passenger Train
  - Monorail, Streetcar or Subway

- Traffic Vehicle – In most communities, each type of traffic vehicle listed in Table 2-2 will be a separate source of noise requiring consideration:
  - Motorcycle
  - Truck
  - Bus
  - Auto

In some northern climates, however, motorcycles may not represent a significant portion of road vehicles and therefore they would not need to be identified as a separate noise source.

Trucks are defined herein as vehicles weighing more than 4500 kilograms (10,000 pounds) which includes all medium and heavy trucks such as dump trucks and interstate vehicles, but does not include light trucks such as bread trucks, vans, or pickups. There are included in the "auto" category. Buses may be considered as one source, or they may be considered as separate sources if there are a large number of different types of buses, for instance, transit, school, and intercity. The "traffic" source listed in Table 2-2 should be included in your community's list of sources if the noise from general street traffic in a particular area cannot be attributed to any particular type of vehicle. The "highway" source listed in Table 2-2 should be included in your community's list of sources only if there are any high-speed, limited access highways. Do not consider a major boulevard as a highway.

- Other Vehicle – Determine which of the following nontraffic motor vehicles are present in your community to a significant degree, i.e., known or suspected to cause noise problems:
  - Service Vehicle (such as garbage truck, street sweeper, snowplow)
  - Emergency Vehicle (such as police, fire, or ambulance)

Service vehicles should be considered a source if there are a large number of operations in residential areas or if much of these operations take place during the nighttime or early morning hours (between 2200 and 0700 hours). An example would be a snowplowing service which takes place every winter morning at 6 a.m. Another example would be early morning refuse collection where the garbage truck frequently operates its trash compactor. Emergency vehicles should be considered a noise source if their sirens and horns are felt to be excessively noisy, or if there are a large number of emergency operations near residential areas. An example would be a major route leading to a hospital and which passes through a residential portion of the community. Noise from off-road vehicles, such as dirt bikes or snowmobiles, which are not operating on a fixed track, might also fit within this category. These sources are not considered further in this manual.

- Domestic — In any community with sufficient density, noise from domestic equipment and people will intrude on neighbors. If a significant number of different kinds of domestic equipment noise sources are found in your community, list each one as a separate source. For instance, in many communities during the summer, both air conditioners and lawn mowers may be in operation extensively, and many complaints or negative attitudes may be observed for both sources. Excessive noise from domestic equipment is usually the result of faulty or inherent design, poor maintenance, or improper operation. There are other domestic noises which people have more immediate personal control over. These may be called "personal" domestic noise sources, such as pets and stereo music. Much of a police department's involvement in noise control concerns such "personal noises" — pets, loud stereo, parties, loud TV sets, or people shouting. Again, a separate noise source can be defined for each of the various types of personal noises if a significant problem is observed for each one. If not, two personal types of noise sources should be defined: "Pets," and "Neighbors' Homes."

Now that you have defined noise zones and noise sources in your community, prepare three tables as shown previously in Figure 2-2. Next, collect data for each of these tables as described in the following sections.

2.2 Collect Complaint Information

The task described in this section is to collect data on the number of households in each of the noise zones complaining about each of the noise sources defined in the community. Complaints regarding noise can come from individual residents or from organizations. They may be received by many parties:

- Operator/Owner (Examples: airport manager, industry headquarters, service department)
- Government Agency (Examples: police, city transportation or environmental department, public utilities)
- Media (Examples: radio/TV talk shows, consumer programs)
- Consumer or Environmental Organizations

Records of the source of the complaint and the location (residence) of the complainer are not often kept; therefore, the task of establishing the total number of complaining households for each noise zone and noise source may be difficult. However, all data that may be available should be sought, and all suitable data which are obtained should be entered into the table.

An example tabulation is shown in Table 2-3. Here the total number of complaining households for each source and zone is shown along with the percent of the total number of households in the zone which the complaining households represent.

Finally, mark those combinations which have "excessive" complaints, i.e., more than 1 percent of households in the zone complain about a source.

2.3 Collect Attitudinal Information

Information on the attitudes of people toward sources of noise in the community is obtained from the EPA Attitudinal Survey.[1] Opinions of respondents toward general neighborhood conditions and toward overall noise conditions in the area are obtained as well as attitudes toward particular noise sources. However, the most important question, for the purposes of this manual, is Question 17 which asks each respondent how annoyed they are by each of 20 categories of noise sources. This question is shown in Figure 2-3. A computerized analysis of the results of the attitudinal survey is usually performed (with EPA assistance). A portion of this analysis will present a cross-tabulation of the frequency of responses for each level of annoyance for each noise source category. Further, a cross-tabulation will appear for each separate noise zone. It will remain to compute,

Table 2-3

Example Tabulation of Complaints Showing Percent of Households in Each Noise Zone Complaining, by Source of Complaints (Number of Complaining Households in Parentheses)

		Noise Zone															
			Aircraft						Major Roadway		Minor Roadway		Residential				
Category	Source	Stationary	A	B	Railroad	Commercial	Industrial	Highway	A	B	Low Volume	High Volume	Low Density	Medium Density	High Density	Very High Density	Total
Stationary Sources	Commercial/Industrial Equipment	5 (10)															
	Construction Noise																
	Entertainment Centers	2 (4)															
Aircraft	Jet																
	Small Plane																
	Helicopter																
Rail	Trains																
Traffic Vehicles	Traffic Noise																
	Motorcycles	1 (2)															
	Trucks																
	Buses																
	Automobiles																
	Highways																
Other Vehicles	Service																
	Emergency																
Domestic	Pets/Animals																
	Neighbors' Homes																
	Air Conditioners																
	Garden Equipment																
	Total																

Note: Circled source/zone combination indicates complaint criteria is exceeded (> 1% complaints).

17. Please turn to card #17. As I read the following list of noise sources, tell me how annoyed you are by each noise source in this area.

READ (a–u). CIRCLE APPROPRIATE CODE.

How Annoyed Are You by Noise from (. . .)?	TREMENDOUSLY ANNOYED	HIGHLY ANNOYED	CONSIDERABLY ANNOYED	MEDIUM ANNOYED	PARTIALLY ANNOYED	A LITTLE ANNOYED	NOT AT ALL ANNOYED
a. Traffic?	1	2	3	4	5	6	7
b. Motorcycles?	1	2	3	4	5	6	7
c. Trucks?	1	2	3	4	5	6	7
d. Buses?	1	2	3	4	5	6	7
e. Automobiles?	1	2	3	4	5	6	7
f. Highways or Freeways?	1	2	3	4	5	6	7
g. Recreational* Vehicles (e.g., Snowmobiles)?	1	2	3	4	5	6	7
h. Garbage Trucks?	1	2	3	4	5	6	7
i. Emergency Vehicles/ Sirens?	1	2	3	4	5	6	7
j. Entertainment Centers (e.g., clubs, movies, places that play live music)?	1	2	3	4	5	6	7
k. Pets/Animals?	1	2	3	4	5	6	7
l. Neighbors' Homes (e.g., noisy stereo, loud talking)?	1	2	3	4	5	6	7
m. Air Conditioners?	1	2	3	4	5	6	7
n. Lawnmowers/ Garden Equipment?	1	2	3	4	5	6	7
o. Jet Airplanes?	1	2	3	4	5	6	7
p. Small Airplanes?	1	2	3	4	5	6	7
q. Helicopters?	1	2	3	4	5	6	7
r. Trains?	1	2	3	4	5	6	7
s. Construction Noise?	1	2	3	4	5	6	7
t. Commercial or Industrial Equipment?	1	2	3	4	5	6	7
u. Other Noise Sources?	1	2	3	4	5	6	7

*Not addressed in this manual.

Figure 2-3. Question 17 from the EPA Attitudinal Survey to Determine How Annoyed People Are by Various Noise Sources

using these tables, the percent of the respondents who said they were either highly or tremendously annoyed by each noise source. This compilation should be done separately for each noise zone. For example:

In the residential noise zone, the breakdown of responses to noise (say, automobiles) was as follows:

Source	Tremendously Annoyed	Highly Annoyed	Considerably Annoyed	Medium Annoyed	Partially Annoyed	A Little Annoyed	Not at All Annoyed
Automobiles	25	35	72	118	112	76	62

Out of a total number of responses to that item of 500, 35 + 25 = 60 reported being either tremendously or highly annoyed by automobiles. This means that

$\frac{60}{500} \times 100\% = 12\%$ of the people are significantly annoyed by automobiles.

Once the percentage figures for each noise source/noise zone combination are computed, assemble the results in tabular format as shown by the example in Table 2-4.

Criteria may now be applied to identify those noise source/noise zone combinations which are problems from an attitudinal standpoint. Mark those combinations which have "excessive" negative attitudes toward noise sources; i.e., those in which at least 4 percent of the households in a zone maintain they are significantly annoyed by a source.

2.4 Collect Acoustical Information

This section assumes that data from the acoustical survey will also be available. A computerized acoustical data reduction is usually performed (with EPA assistance).[26] The particular item of interest for this manual is the component noise source "equivalent impact" levels for each noise source for each noise zone.

These source levels are spatial (numerical) averages of source levels observed at acoustical survey measurement locations. At those measurement locations where a source was not intrusive enough to be identified, the minimum impact level for the

Table 2-4

Example Tabulation of Surveyed Attitudes Showing Percent of Households in Each Noise Zone Significantly Annoyed by Each Noise Source (Number of Households in Parentheses)

Category	Source	Noise Zone															Total
			Aircraft						Major Roadway		Minor Roadway		Residential				
		Stationary	A	B	Railroad	Commercial	Industrial	Highway	A	B	Low Volume	High Volume	Low Density	Medium Density	High Density	Very High Density	
Stationary Sources	Commercial/Industrial Equipment	4 (8)															
	Construction Noise																
	Entertainment Centers	1 (2)															
Aircraft	Jet																
	Small Plane																
	Helicopter																
Rail	Trains																
Traffic Vehicles	Traffic Noise																
	Motorcycles	8 (16)															
	Trucks																
	Buses																
	Automobiles																
	Highways																
Other Vehicles	Service																
	Emergency																
Domestic	Pets/Animals																
	Neighbors' Homes																
	Air Conditioners																
	Garden Equipment																
Total																	

Note: Circled source/zone combination indicates attitudinal criteria exceeded.

corresponding type of land Use (see Table 1-1) was substituted (instead of zero!) in the averaging process. Hence, the term "equivalent impact." This procedure was designed to be entirely consistent with the methodology presented in this manual.

Figure 2-4 illustrates the form of the output of interest here from the computer analysis of the acoustical survey. The L_{dn} is used as a criterion for identifying a troublesome noise source; the L_d and L_n will be used later as input to the Noizop computer program. A noise level of 0 dB indicates that that noise source was not identified in the noise zone.

Some manipulation of the results of the acoustical survey may be necessary because the list of noise sources for the acoustical survey is not identical with the list for the attitudinal survey used in this manual. Refer to Table 2-5 for resolving these differences.

Some noise source levels not measured in the acoustical survey (i.e., entertainment centers, air conditioners, etc.) will have to be obtained by other means. If data from previous acoustical surveys is not available, an individual from the local noise control office may be sent into the community with a sound level meter to gather typical noise levels for these sources. Note that these data will have to be translated into daytime and nighttime noise levels (L_d and L_n, respectively) and day-night levels, L_{dn}. An alternate approach is to estimate the noise levels for these sources using available prediction techniques. A description of these techniques is beyond the scope of this manual.

In addition, the EPA acoustical survey provides no source level information for the airport and railroad noise zones. For these zones, the procedure outlined in Table 2-6 should be used. This table provides nominal noise levels for jet aircraft and rail noise sources to be used for source noise levels in their respective noise zones. A simple algorithm is also provided to estimate levels for other sources in these zones.

```
NOISE ZONE:  R            COMPONENT SOURCE EQUIVALENT IMPACT LEVELS

       LDN:  61.8
                            SOURCE                      LD        LN        LDN


                          EMER. VEH.                    .0      42.2       47.9

                          SMALL PLANE                 53.8      41.8       53.1

                          JET                         53.6      43.0       53.4

                          HELICOPTER                    .0      42.4       48.2

                          RAILROAD                      .0      38.8       44.5

                          TRUCK                       56.0      41.0       54.7

                          AUTO                        56.3      41.4       55.1

                          BUS                         54.4      42.4       53.8

                          MOTORCYCLE                    .0      42.4       48.2

                          SERVICE VEHICLES              .0      41.6       47.4

                          OFF. RD. VEH.               54.3      42.4       53.7

                          CONST. EQUIP.               54.0      42.4       53.5

                          YARD MAINT. EQ.               .0      42.4       48.2

                          FACTORY EQUIP.              53.9      42.4       53.4

                          HOUSEHOLD EQUIP.            53.9      42.4       53.4

                          DOG                         52.8      41.9       52.5

                          LOUD SPEAKERS                 .0      42.4       48.2


                          UNIDENTIFIABLE              53.7      39.2       52.5
```

Figure 2-4. Example Output of Computerized Reduction of Acoustical Survey Data Illustrating Component Source Levels

Table 2-5

Comparison of Noise Sources Used in
EPA Acoustical Survey Manual[2] with Those Used in this Manual

Noise Source Category	Noise Source	Acoustical Survey Noise Source *
Stationary	Commercial/Industrial	Factory Equip.
	Construction	Const. Equip.
	Entertainment Center	——
Aircraft	Jet	Jet
	Small Plane	Small Plane
	Helicopter	Helicopter
Rail	Trains	Railroad
Traffic Vehicle	Traffic Noise	——
	Motorcycle	Motorcycle
	Truck	Truck
	Bus	Bus
	Automobile	Auto
	Highway	——
Other Vehicles	Service	Service Vehicles
	Emergency	Emer. Veh.
Domestic	Pets/Animals	Dog
	Neighbors' Homes	Household Equip.
	Air Conditioners	——
	Garden Equipment	Yard Maint. Eq.

*See Figure 2-4.

Table 2-6

Estimated Noise Levels for Noise Zones with No Source-Specific Data

a) For L_{dn}, use:

	Jets	Rail	All Other
Airport Zone A	75 dB	(1)*	(1)
Airport Zone B	65 dB	(1)	(1)
Railroad	(1)	65 dB	(1)

b) For L_d (2), use:

	Jets	Rail	All Other
Airport Zone A	74 dB	(1)	(1)
Airport Zone B	64 dB	(1)	(1)
Railroad	(1)	64 dB	(1)

c) For L_n (2), use:

	Jets	Rail	All Other
Airport Zone A	66 dB	(1)	(1)
Airport Zone B	56 dB	(1)	(1)
Railroad	(1)	56 dB	(1)

NOTE: L_{dn} is used in the criteria evaluation procedure.

L_d and L_n are used as input to the Noizop computer program.

*(see additional notes on following page)

Table 2-6 (Continued)

(1) For these values, use the expression

$$L = (F_R \cdot L_R) + (F_{C/I} \cdot L_{C/I})$$

where:

L	is the resultant level, either L_{dn}, L_d, or L_n.
F_R	is the fraction of the land use in the noise zone of interest (Airport or Railroad) that is residential. ($F_R + F_{C/I} = 1$)
L_R	is the noise level (L_{dn}, L_d, or L_n) of the noise source of interest in the residential noise zone.
$F_{C/I}$	is the fraction of the land use in the noise zone of interest (Airport or Railroad) that is either commercial or industrial.
$L_{C/I}$	is the noise level of the noise source of interest in the commercial or industrial noise zone. If the two zones are considered separately, use a numerical average value for the source level.

(2) Assumes $L_d = L_n + 8$ dB (see Table 1-1)

Once all the source contribution values for each zone have been obtained, they may be arranged in tabular form as shown in Table 2-7. As shown in the table, mark those noise source/noise zone combinations which have an L_{dn} exceeding 55 dB. These combinations denote sources and zones which have "excessive" noise problems and which are candidates for the application of noise abatement techniques.

2.5 Select Problem Areas to Investigate

Select the final set of problem areas to be investigated by combining Tables 2-3, 2-4, and 2-7. You have previously marked those noise source/noise zone combinations in each table which exceed the criteria established in Figure 2-1 for complaints, attitudes, and noise levels, respectively. Gather the complaint, attitude, and noise level values for each of the marked combinations into a master source/location impact matrix as shown in Table 2-8. All sources identified in the matrix as being the cause of excessive noise problems will be considered for noise abatement treatment. In all zones identified by the matrix as being the location of excessive noise problems, the costs and effectiveness of various noise abatement measures will be investigated. The procedures for selecting abatement measures and providing related input data for the cost-effectiveness model are discussed in the next chapter.

Table 2-7

Example Tabulation of Noise Levels (L_{dn}) Showing Contribution of Sources in Each Noise Zone

		Noise Zone															
			Aircraft						Major Roadway		Minor Roadway		Residential				
Category	Source	Stationary	A	B	Railroad	Commercial	Industrial	Highway	A	B	Low Volume	High Volume	Low Density	Medium Density	High Density	Very High Density	Total
Stationary Sources	Commercial/Industrial Equipment	(59)															
	Construction Noise																
	Entertainment Centers	42															
Aircraft	Jet																
	Small Plane																
	Helicopter																
Rail	Trains																
Traffic Vehicles	Traffic Noise																
	Motorcycles	(62)															
	Trucks																
	Buses																
	Automobiles																
	Highways																
Other Vehicles	Service																
	Emergency																
Domestic	Pets/Animals																
	Neighbors' Homes																
	Air Conditioners																
	Garden Equipment																
Total																	

Note: Circled source/zone combination indicates noise level criteria is exceeded. ($L_{dn} > 55$ dB)

Table 2-8

Example Impact Matrix Showing Source and Location (Noise Zone) of "Excessive Impacts" Identified from Tables 2-3, 2-4 and 2-7

		Noise Zone															
			Aircraft						Major Roadway		Minor Roadway		Residential				
Category	Source	Stationary	A	B	Railroad	Commercial	Industrial	Highway	A	B	Low Volume	High Volume	Low Density	Medium Density	High Density	Very High Density	Total
Stationary Sources	Commercial/Industrial Equipment	C															
	Construction Noise																
	Entertainment Centers	C															
Aircraft	Jet																
	Small Plane																
	Helicopter																
Rail	Trains																
Traffic Vehicles	Traffic Noise																
	Motorcycles	A,N															
	Trucks																
	Buses																
	Automobiles																
	Highways																
Other Vehicles	Service																
	Emergency																
Domestic	Pets/Animals																
	Neighbors' Homes																
	Air Conditioners																
	Garden Equipment																
	Total																

C - Complaint Criteria Exceeded. A - Attitudinal Criteria Exceeded. N - Noise Level Criteria Exceeded.

3.0 QUANTIFY ALTERNATIVES

In Section 1.2, a brief outline of the computer program Noizop was presented. In this chapter, methods of preparing data for the operation of Noizop are described. Four preparatory tasks are involved. They are considered in turn in the following sections:

3.1 Identify Appropriate Alternatives
3.2 Select Year to Apply Optimization Model
3.3 Prepare Community Data
3.4 Estimate Costs and Noise Reductions of Alternatives

3.1 Identify Appropriate Alternatives

A list of "problem" noise sources was derived in Chapter 2 based on complaint histories, attitudinal data, and acoustical measurements. The purpose of this task is to compile a list of noise abatement alternatives for possible application to these noise sources. In order to minimize computational effort, both by hand and by computer, only those alternatives will be listed which are expected to be effective in solving the particular problems identified in Chapter 2.

A list of abatement alternatives which local governments may apply to community noise problems is shown in Table 3-1. For each alternative, an illustrative example is given showing how the alternative might be applied in a typical community. Study these alternatives to familiarize yourself with the options which are available. Then, complete the following steps in order to obtain a list of abatement alternatives which are the most appropriate for your community.

Step 1. Make a list of "problem sources" from Table 2-8. Include all sources which have been identified as producing an excessive impact on one or more noise zones in the community.

Step 2. Add to the list of identified problem sources any additional sources of noise which are known to cause problems in the community, but which may have been missed by the procedures of Chapter 2. Do not guess. Rather, use

Table 3-1

List of Abatement Alternatives Which Local Governments May Apply to Community Noise Sources

Abatement Alternatives	Example *
Operational Restrictions	
Noise Standard	Motor vehicles shall not exceed 86 dB at 15m in speed zones above 64km/h (40 mph).
Operational Controls	1. Speed limit in residential areas changes from 72 to 56km/h (45 to 35 mph). 2. Vehicles shall not operate with excessive acceleration (except where safety requires).
Area Restrictions	No thru-trucks allowed in hillside area.
Time Restrictions	No loud music exceeding 70 dB at property line allowed after 10 P.M.
Permits	On all construction projects exceeding $10,000 value, equipment must meet municipal noise standard X.
Land Use Restrictions	
Barriers	Construct barrier between highway and school.
Building Insulation	Insulate all buildings near airport where $L_{dn} > 75$ dB.
Compensation	Reimburse residents under flight path for lowered property values.
Population Relocation	Relocate residents living in airport areas where $L_{dn} > 75$ dB.
Planning/Zoning	1. Build new highway through industrial area instead of residential area. 2. Restrict future housing developments near airport.
Building Codes	Extra insulation required in zones where $L_{dn} > 65$ dB.
Tax Measures	
Tax Incentives	Commercial establishments installing quiet outdoor furnaces receive tax break.
Tax Penalty	Plants are charged $500 per dB in excess of 70 dB (L_{dn}) measured at property line per year.
New Product Regulations	
Noise Standard	New lawn mowers sold in the city may not exceed 75 dB at 7.5 m.
Labeling	New vacuum cleaners sold in the city must be acoustically labeled.
Equipment Standard	
Maintenance	Registered automobiles must be inspected for proper maintenance once every two years.
Retrofit	All motorcycles must have a muffler that produces an insertion loss of at least 20 dB.
Other Alternatives	
Education	1. Broadcast once-a-month radio programs to help consumer choose quiet products. 2. Inform local airport and pilots of noise-sensitive areas.
Complaint Mechanism	Establish noise hotline in cooperation with police.

* These examples are illustrative and may not completely describe details which must be specified if the abatement alternative is to be properly established. Products mentioned as targets of abatement action may not be the most important noise sources to control.

information such as newspaper articles, TV interviews, and topics of public meetings to determine whether there are additional sources of noise which the community is disturbed about. For instance, the acoustical and attitudinal surveys of the community might have been taken during the winter, whereas a noise source such as a fairground may only be in operation for 2 weeks during the summer. It is also possible that the affected population residing close to the fairgrounds is small, compared to the total population of the noise zone, such that the complaint criteria level is not exceeded.

Step 3. Remove from the list of identified problem sources any for which, based on community consensus, treatment is not desired. For instance, an event such as a fireworks display is typically regarded by most segments of a community as beneficial and is not therefore subject to noise abatement. Consequently, if a source such as this was identified in Chapter 2 as a noise problem, it should be removed at this time from further consideration. Again, do not guess. Utilize only published or public information on which to base any decision to remove sources which have previously been identified as problems.

Step 4. Prepare a list of remaining abatement alternatives which are expected to be effective in reducing the noise from the problem sources in the community. Alternatives which are applicable to each problem source are identified using Table 3-2 as follows. First, underline your community's problem sources in the left-hand column of the table. Next, circle all dark crosses lying in the same rows as those sources which you have identified as problems.

Finally, circle with a heavy line the heading for all those alternatives which have a circled dark cross in their column. An example of this procedure is shown in Table 3-3. The heavily circled alternatives are expected to be the most effective measures for reducing your community's noise problems.

Table 3-2

Countermeasures Which Local Governments Can Apply to Community Noise Sources

Category	Source	Operational Restrictions					Land Use Controls					
		Noise Standard	Operational Controls	Area Restrictions	Time Restrictions	Permits	Barriers	Building Insulation	Compensation	Population Relocation	Planning & Zoning	Building Codes
Stationary Sources	Commercial/Industrial Equipment	✖	✖	▨	⌘	⌘	✖	✖	⌘	⌘	✖	✖
	Construction Noise	⌘	✖	▨	✖	✖	⌘	✖	▨	▨	▨	✖
	Entertainment Centers	✖	✖	▨	✖	✖	⌘	✖	⌘	⌘	✖	✖
Aircraft	Jet	⌘	✖	⌘	✖	⌘	▨	✖	✖	✖	✖	✖
	Small Plane	⌘	✖	⌘	✖	▨	▨	✖	⌘	⌘	✖	✖
	Helicopter	⌘	✖	⌘	✖	▨	▨	✖	⌘	⌘	✖	✖
Rail Vehicles	Trains	⌘	⌘	▨	⌘	▨	✖	✖	⌘	⌘	✖	✖
Traffic Vehicles	Traffic Noise (1)	⌘	⌘	⌘	⌘	▨	⌘	⌘	▨	▨	⌘	✖
	Motorcycles	✖	✖	⌘	▨	▨	⌘	✖	▨	▨	▨	✖
	Trucks	⌘	⌘	⌘	⌘	▨	⌘	⌘	▨	▨	⌘	⌘
	Buses	⌘	⌘	⌘	⌘	▨	⌘	⌘	▨	▨	⌘	⌘
	Automobiles	⌘	⌘	▨	▨	▨	⌘	⌘	▨	▨	▨	⌘
	Highway & Freeway (1)	✖	✖	⌘	▨	▨	✖	✖	⌘	⌘	✖	✖
Other Vehicles	Garbage Trucks	⌘	✖	▨	✖	▨	▨	✖	▨	▨	▨	✖
	Emergency Vehicles/ Sirens	⌘	✖	▨	⌘	▨	▨	✖	▨	▨	⌘	✖
Domestic	Pets/Animals	⌘	▨	▨	⌘	▨	▨	✖	▨	▨	▨	✖
	Noise from Within Neighbors' Homes	⌘	▨	▨	⌘	▨	▨	✖	▨	▨	▨	✖
	Air Conditioners	⌘	✖	⌘	✖	⌘	▨	✖	▨	▨	▨	✖
	Lawnmowers/Garden Equipment	⌘	✖	⌘	✖	⌘	▨	✖	▨	▨	▨	✖
	Implementation Time	Short Time Frame									Long Time Frame	
	Benefit	Exterior Noise Level Reduction						Interior Reduction	Sensitivity Reduction	Reduction of Exposed Population		Interior Reduction

*See next page for key.

Table 3-2 (Continued)

Category	Source	Tax Measures		New Product Regulations		Equipment Standards		Other Countermeasures	
		Property Tax Incentives	Business Tax Penalty	Noise Standard	Labeling	Maintenance	Retrofit	Education	Complaint Mechanism
Stationary Sources	Commercial/Industrial Equipment	✖	✖	▨	▨	⌘	⌘	⌘	✖
	Construction Noise	⌘	⌘	✖	▨	✖	⌘	⌘	✖
	Entertainment Centers	⌘	⌘	▨	▨	▨	▨	⌘	✖
Aircraft	Jet	▨	⌘	⌘ (2)	▨	▨	✖	✖	✖
	Small Plane	▨	⌘	⌘ (2)	▨	▨	⌘	✖	✖
	Helicopter	▨	⌘	⌘ (2)	▨	▨	⌘	⌘	⌘
Rail Vehicles	Trains	⌘	⌘	▨	▨	⌘	⌘	⌘	✖
Traffic Vehicles	Traffic Noise (1)	▨	▨	✖	⌘	✖	✖	▨	✖
	Motorcycles	▨	▨	✖	⌘	✖	✖	✖	⌘
	Trucks	▨	⌘	✖	⌘	✖	✖	✖	⌘
	Buses	▨	⌘	✖	⌘	✖	✖	✖	✖
	Automobiles	▨	▨	✖	⌘	✖	✖	✖	⌘
	Highway and Freeway (1)	▨	▨	⌘	⌘	⌘	⌘	▨	⌘
Other Vehicles	Garbage Trucks	▨	⌘	✖	▨	⌘	⌘	✖	✖
	Emergency Vehicles/Sirens	▨	▨	✖	▨	▨	⌘	✖	✖
Domestic	Pets/Animals	▨	▨	▨	▨	▨	▨	✖	✖
	Noise from Within Neighbors' Homes	▨	▨	▨	▨	▨	▨	✖	✖
	Air Conditioners	⌘	▨	✖	⌘	⌘	⌘	✖	✖
	Lawnmowers/Garden Equipment	⌘	▨	✖	⌘	⌘	⌘	✖	✖
	Implementation Time	Long Time Frame							Short Time Frame
	Benefit	Exterior Noise Level Reduction						Mixture Benefits	

✖ Obvious or known to be effective.

⌘ Potentially applicable.

▨ Not applicable or feasible.

(1) Includes countermeasures applicable to roadway vehicles: trucks, autos, etc.

(2) Cooperation from FAA necessary.

All of them will be considered in the cost-effectiveness model. Prepare a list of these alternatives for each source. There are 11 such alternatives shown in the example. Now return to the table and draw a box around all the light crosses lying in the same rows as the identified sources. Then draw a box around the heading for those alternatives which have a light cross boxed in their column, but which have no dark crosses circled (i.e., the alternative has not been circled). An example of this procedure is also shown in Table 3-3. These additional alternatives are potentially applicable to the problems in your community, but their application is optional. Make a list of these optional alternatives. There are five of these optional alternatives shown in the example.

Step 5. Choose from the list of "potentially applicable" alternatives (with boxes drawn around them) only those alternatives which you wish to consider in the cost-effectiveness model. For example, you may wish to consider building barriers as an abatement measure to reduce noise from a construction site, although this alternative is not expected to be very effective in this particular case.

Step 6. Add to the list of alternatives to be analyzed by the computer model any additional alternatives which may not have been selected up to this point, but which the community wishes to consider. For instance, the labeling of new lawn mowers sold in the community with a tag showing the noise level they produce at a reference distance may not be very effective in actually reducing community noise levels. However, if an extensive local noise labeling program is desired or is already underway, it may be appropriate to include this measure in the list of applicable alternatives.

Table 3-3

Identification of Specific Measures for Treating Problem Noise Sources*

		Operational Restrictions							Land Use Controls			
Category	Source	Noise Standard	Operational Controls	Area Restrictions	Time Restrictions	Permits	Barriers	Building Insulation	Compensation	Population Relocation	Planning & Zoning	Building Codes
Stationary Sources	Commercial/Industrial Equipment	✖	✖		✕	✕	✖	✖	✕	✕	✖	✖
	Construction Noise	⊠	⊗		⊗	⊗	⊠	⊗				⊗
	Entertainment Centers	✖	✖		✖	✖	✕	✖	✕	✕	✖	✖
Aircraft	Jet	✕	✖	✕	✖	✕		✖	✖	✖	✖	✖
	Small Plane	✕	✖	✕	✖			✖	✕	✕	✖	✖
	Helicopter	✕	✖	✕	✖			✖	✕	✕	✖	✖
Rail Vehicles	Trains	✕	✕		✕		✖	✖	✕	✕	✖	✖
Traffic Vehicles	Traffic Noise (1)	✕	✕	✕	✕		⊠	✕			✕	✖
	Motorcycles	⊗	⊗	⊠			✕	⊗				⊗
	Trucks	✕	✕	✕	✕		✕	✕			✕	✕
	Buses	✕	✕	✕	✕		✕	✕			✕	✕
	Automobiles	✕	✕				✕	✕				✕
	Highway & Freeway (1)	✖	✖	✕			✖	✖	✕	✕	✖	✖
Other Vehicles	Garbage Trucks	⊠	⊗		⊗			⊗				⊗
	Emergency Vehicles/ Sirens	✕	✖		✕			✖			✕	✖
Domestic	Pets/Animals	✕			✕			✖				✖
	Noise from Within Neighbors' Homes	✕			✕			✖				✖
	Air Conditioners	✕	✖	✕	✖	✕		✖				✖
	Lawnmowers/Garden Equipment	✕	✖	✕	✖	✕		✖				✖
	Implementation Time	Short Time Frame									Long Time Frame	
	Benefit	Exterior Noise Level Reduction						Interior Reduction	Sensitivity Reduction	Reduction of Exposed Population		Interior Reduction

*See next page for key.

Table 3-3 (Continued)

Category	Source	Tax Measures		New Product Regulations		Equipment Standards		Other Countermeasures	
		Property Tax Incentives	Business Tax Penalty	Noise Standards	Labeling	Maintenance	Retrofit	Education	Complaint Mechanism
Stationary Sources	Commercial/Industrial Equipment	✖	✖	▨	▨	⌘	⌘	⌘	✖
	Construction Noise	[⌘]	[⌘]	⊗	▨	⊗	[⌘]	[⌘]	⊗
	Entertainment Centers	⌘	⌘	▨	▨	▨	▨	⌘	✖
Aircraft	Jet	▨	⌘	⌘ (2)	▨	▨	✖	✖	✖
	Small Plane	▨	⌘	⌘ (2)	▨	▨	⌘	✖	✖
	Helicopter	▨	⌘	⌘ (2)	▨	▨	⌘	⌘	✖
Rail Vehicles	Trains	⌘	⌘	▨	▨	⌘	⌘	⌘	⌘
Traffic Vehicles	Traffic Noise (1)	▨	▨	✖	⌘	✖	✖	▨	✖
	Motorcycles	▨	▨	⊗	[⌘]	⊗	⊗	⊗	⊗
	Trucks	▨	⌘	✖	⌘	✖	✖	✖	⌘
	Buses	▨	⌘	✖	⌘	✖	✖	✖	⌘
	Automobiles	▨	▨	✖	⌘	✖	✖	✖	✖
	Highway and Freeway (1)	▨	▨	⌘	⌘	⌘	⌘	▨	⌘
Other Vehicles	Garbage Trucks	▨	[⌘]	⊗	▨	[⌘]	[⌘]	⊗	[⌘]
	Emergency Vehicles/Sirens	▨	▨	✖	▨	▨	⌘	✖	✖
Domestic	Pets/Animals	▨	▨	▨	▨	▨	▨	✖	✖
	Noise from Within Neighbors' Homes	▨	▨	▨	▨	▨	▨	✖	✖
	Air Conditioners	⌘	▨	✖	⌘	⌘	⌘	✖	✖
	Lawnmowers/Garden Equipment	⌘	▨	✖	⌘	⌘	⌘	✖	✖
	Implementation Time	Long Time Frame							Short Time Frame
	Benefit	Exterior Noise Level Reduction						Mixture Benefits	

✖ Obvious or known to be effective.

⌘ Potentially applicable.

▨ Not applicable or feasible.

(1) Includes countermeasures applicable to roadway vehicles: trucks, autos, etc.

(2) Cooperation from FAA necessary.

Step 7. Remove from the list any alternatives which are, based on local circumstances, considered to be impossible to implement. For instance, if there is going to be no possibility of funding for noise enforcement purposes, then alternatives such as noise standards, equipment maintenance requirements, and operational controls would be candidates for removal from the list. Do not eliminate potential abatement alternatives at this time merely because they may seem at first glance to be too costly or ineffective in reducing noise. The decision regarding which alternatives are the most cost-effective should be made after obtaining results from further analysis.

Step 8. Use Table 3-4(a) to help identify community reactions toward each alternative. Question 21 of the EPA Attitudinal Survey Questionnaire asks whether the respondent would support a number of suggested noise abatement activities. The percent of respondents who support each suggested activity is tabulated in the Attitudinal Survey analysis computer output. This data package should be available from the EPA or the agency conducting the survey. Obtain these percentages for the entire community. For each suggested alternative in Table 3-4(a), enter the percentage of people who support the suggestion in each open square under the suggestion heading. An example is shown in Table 3-4(b). Now, for each abatement alternative which is a candidate for implementation up to this point, note the percent of people who say they would support it in the right-hand column (as shown in Table 3-4(b) for two hypothetically recommended alternatives). In some cases, such as for equipment standards, two types of activities suggested in the questionnaire are applicable to a single abatment alternative, and the percent of people who support both suggestions should be considered. For instance, people may support a vehicle maintenance program because it would make sources quieter (Suggestion a) but they may not support the program if it provided "fines for making too much noise" (Suggestion e).

Table 3-4(a)

Worksheet for Identifying Community Attitudes Toward Abatement Alternatives

Abatement Alternatives	Percent Supporting Given Suggestion *								Percent Supporting Recommended Alternatives
	a	b	c	d	e	f	g	h	
	Makes Noise Sources Quieter	Planning and Zoning	Bldg. Codes	Curfews	Fines for Making Too Much Noise	Barriers	Public Information Campaign	Other	
Operational Restrictions									
Noise Standard		▨	▨	▨		▨	▨	▨	
Operational Controls		▨	▨	▨	▨	▨	▨	▨	
Area Restrictions	▨		▨	▨	▨	▨	▨	▨	
Time Restrictions	▨	▨	▨		▨	▨	▨	▨	
Permits	▨	▨	▨	▨		▨	▨	▨	
Land Use Restrictions									
Barriers	▨	▨	▨	▨	▨		▨	▨	
Building Insulation	▨	▨		▨	▨	▨	▨	▨	
Compensation	N/A **								
Population Relocation	N/A								
Planning/Zoning	▨		▨	▨	▨	▨	▨	▨	
Building Codes	▨	▨		▨	▨	▨	▨	▨	
Tax Measures									
Tax Incentives	N/A								
Tax Penalty	▨	▨	▨	▨		▨	▨	▨	
New Product Regulations									
Noise Standard		▨	▨	▨	▨	▨	▨	▨	
Labeling	▨	▨	▨	▨	▨	▨		▨	
Equipment Standard									
Maintenance		▨	▨	▨		▨	▨	▨	
Retrofit		▨	▨	▨		▨	▨	▨	
Other Alternatives									
Education	▨	▨	▨	▨	▨	▨		▨	
Complaint Mechanism	▨	▨	▨	▨	▨	▨		▨	

*From Q21 of Attitudinal Survey.

**N/A - No suggestions in Attitudinal Survey questionnaire are applicable to this abatement alternative.

Table 3-4(b)

Worksheet for Identifying Community Attitudes Toward Abatement Alternatives

	Percent Supporting Given Suggestion *								
	a	b	c	d	e	f	g	h	
Abatement Alternatives	Makes Noise Sources Quieter	Planning and Zoning	Bldg. Codes	Curfews	Fines for Making Too Much Noise	Barriers	Public Information Campaign	Other	Percent Supporting Recommended Alternatives
Operational Restrictions									
[✓ Noise Standard]	40				35				35-40
Operational Controls	40								
Area Restrictions		10							
Time Restrictions				25					
Permits					35				
Land Use Restrictions									
Barriers						15			
Building Insulation			10						
Compensation	N/A **								
Population Relocation	N/A								
Planning/Zoning		10							
Building Codes			10						
Tax Measures									
Tax Incentives	N/A								
Tax Penalty					35				
New Product Regulations									
Noise Standard	40								
[✓ Labeling]							5		5
Equipment Standard									
Maintenance	40				35				
Retrofit	40				35				
Other Alternatives									
Education							5		
Complaint Mechanism							5		

*From Q21 of Attitudinal Survey.

**N/A - No suggestions in Attitudinal Survey questionnaire are applicable to this abatement alternative.

NOTE: Circled alternatives are hypothetically recommended in this example using the procedures presented earlier in this shapter. This example indicates significant community support for noise standards, but little support for a labeling program.

Step 9. After completing the above procedure, note which alternatives are supported by the community and those which are not. Remove any abatement alternative which the community clearly will not support. In any decision to remove an alternative from further consideration, additional sources of attitudinal information other than these survey data may be used if they are available. Similarly, based on other results from the attitudinal survey or other sources of information, give strong consideration to including any additional alternatives which the community is willing to support.

The result of executing the nine steps just presented is that a list of feasible candidate noise abatement alternatives is developed. The community should be prepared to implement these measures to some degree. These measures are also expected to be effective in reducing the noise problems faced by the community. The next task is to select a time period (year) in the future in which the costs and effectiveness of these abatement alternatives are to be compared.

3.2 Select Year to Apply Optimization Model

The first step in any cost analysis is to decide what time frame will be utilized. Once a time frame is selected, it is applied to all alternatives under consideration to ensure that they are compared on an equal basis. The cost-effectiveness model can be applied only to one selected target year. The implicit assumption is that the implementation of noise countermeasures during the time period from the base year to the target year will gradually reduce adverse noise effects to the level projected for the target year. Specific reasons for selecting a particular target year may be varied; some cities may desire to coordinate noise control strategies with their long-term master plan and may therefore desire to evaluate a period of up to 30 years. In other cases, political pressures may dictate the necessity of obtaining quick cost-effective solutions so that a target year only a few years from the base would be selected. If noise countermeasures are considered which involve a considerable time lag in their effectiveness (e.g., zoning and building codes), the target year must be selected such that their effect can be included. Resources permitting, very valuable insight into noise abatement strategies can be gained by repeating the entire analysis for 2 or 3 target years. In fact, the optimum allocation of funds among the various noise abatement countermeasures may vary depending on the target year selected.

Detailed guidelines for the selection of the year for which costs and effectiveness will be compared and involve a number of considerations as follows:

- Population projections/growth rate/building activity
- Time lag for alternatives selected
- Future technology
- Availability of future funding
- Time frame for master plan
- Necessity for quick solutions
- Projected timing of expenditures (discounted annual costs)

Population Projections/Growth Rate/Building Activity

If the population of the community is growing rapidly, it is advisable to select a year which will follow the peak growth period so that the analysis will apply to a more stabilized environment. For low growth conditions, a short-term analysis will suffice. When future growth conditions are difficult to forecast, a short-term analysis is recommended in order to minimize the uncertainties associated with predicting the effects for a medium or long-term analysis.

Time Lag for Alternatives Selected

Certain noise abatement alternatives, especially zoning and building codes, are long-term solutions only. As a result, their effectiveness cannot be properly assessed unless they are analyzed for a projected period 5 to 15 years after implementation. This is because zoning and building codes are not retroactive and do not affect existing buildings. Vacant lots and properties with buildings over 50 years old will be the first to comply with such regulations. The time lag for effectiveness of these countermeasures thus depends on the growth rate and the proportion of vacant land or older buildings in the community.

Future Technology

Future technology could make both cost and effectiveness estimates obsolete for some alternatives. This possibility is most likely with a long-term analysis. If the noise abatement options under consideration involve industries which emphasize research and development (such as the aircraft or motor vehicle industries), a short-term analysis is more advisable because of the uncertainties surrounding future noise abatement technology which these industries might employ.

Availability of Future Funding

It may be desirable to coordinate the cost-effectiveness analysis with the city's budget preparation so that future funding for noise abatement activities can be incorporated into the budget. For some cities, this will necessitate only a short-term (1 to 5 years after initial implementation) analysis. However, other cities may also prepare medium and long-term budgets which make a longer term cost-effectiveness analysis desirable.

Time Frame for Master Plan

Master plans are prepared for varying periods of time – usually from 5 to 30 years. The year chosen for analysis should fall within the period covered by the master plan. This will ensure maximum coordination among such factors as growth rate, zoning regulations, etc.

Necessity for Quick Solutions

If the emphasis is on immediate solutions to current noise problems, a short-term analysis may be adequate. As the emphasis shifts to control of anticipated future noise problems, a longer term analysis will be advisable.

Projected Timing of Expenditures

Since future costs are discounted but future effectiveness is not, the cost-effectiveness ratio of a given countermeasure can vary from year to year, so different results may be obtained depending upon the year chosen for analysis and the particular year(s) in which certain expenditures are made for various alternatives. Figure 3-1 illustrates this issue for one hypothetical alternative. After scheduling one-time expenditures such as building insulation, land acquisition, and noise barriers, the analysis year can be chosen. The year selected should be a period of time after these one-time expenditures have been incurred.

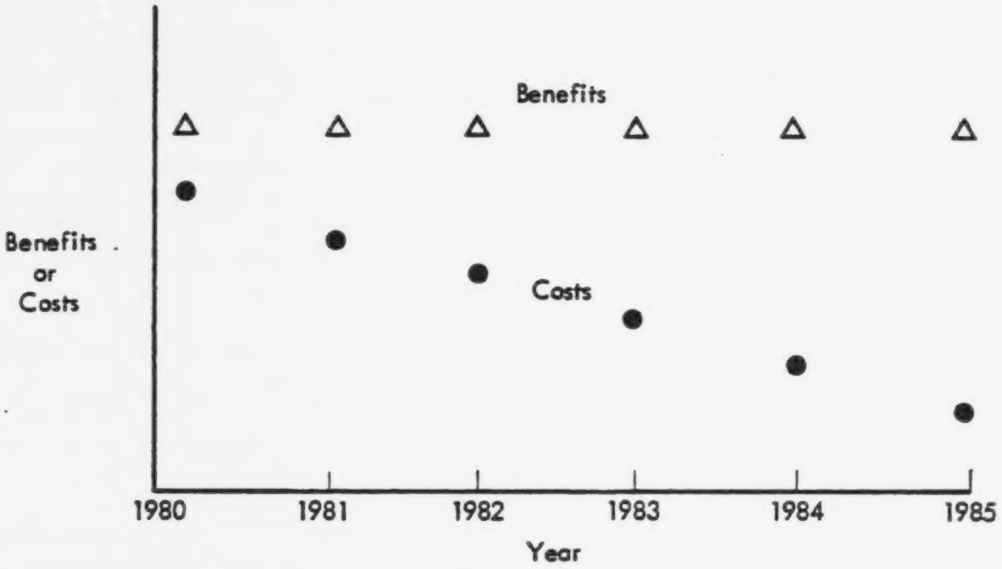


Figure 3-1. Annual Noise Reduction Benefits and Discounted Annual Costs: An Illustration of the Change in Cost-Effectiveness Due to Timing of Expenditures

Summary

Using the format illustrated in Table 3-5, check the applicable boxes after determining (based on each of the decision factors) whether a short-term or long-term analysis is most advisable. If all factors are equal in importance, adopt the time frame which receives the most check marks. Once this is done, if a short-term analysis is indicated, select a year 1 to 5 years from the date the alternatives will first be implemented. For a long-term analysis, the year chosen should be 6 to 15 years from the date of implementation.

Table 3-5

Example Selection of Short-Term or Long-Term Analysis Year

	Short-Term	Decision Factor	Long-Term	
✓	Low Growth Conditions, Future Growth Difficult to Forecast	Growth Rate	Population is Growing Rapidly	
	Options are Effective Upon Implementation	Time Lag for Options	Options Include Zoning and Building Codes	✓
✓	Options Involve Industries which Emphasize Research and Development	Future Technology	Options are Essentially Independent of New Technology	
✓	Short-Term Budget (1 to 5 years)	Availability of Future Funding	Long-Term Budget (over 5 years)	
	Planning Period is Less than 5 Years	Time Frame for Master Plan	Planning Period is Over 5 Years	✓
	Emphasis on Immediate Solutions to Current Noise Problems	Necessity for Quick Solutions	Emphasis on Control of Anticipated Future Noise Problems	✓
✓	One-Time Expenditures Scheduled Within 1 to 5 Years	Projected Timing of Expenditures	One-Time Expenditures Scheduled After 5 Years	
4	Total Number of Short-Term Factors Checked		Total Number of Long-Term Factors Checked	3
✓	Term Length Chosen			

It is recognized that in many cases all seven decision factors will not be equal in importance. When this occurs, it may be desirable to check only those decision factors which are most important to the community such as growth rate or necessity for quick solutions, and then select the time frame indicated by these important factors.

3.3 Prepare Community Data

The preparation of community data for input to the optimization model is discussed in this section in four parts:

- 3.3.1 Divide Community Into Cells
- 3.3.2 Estimate Cell Populations
- 3.3.3 Establish Baseline Noise Levels
- 3.3.4 Prepare Land Use Information

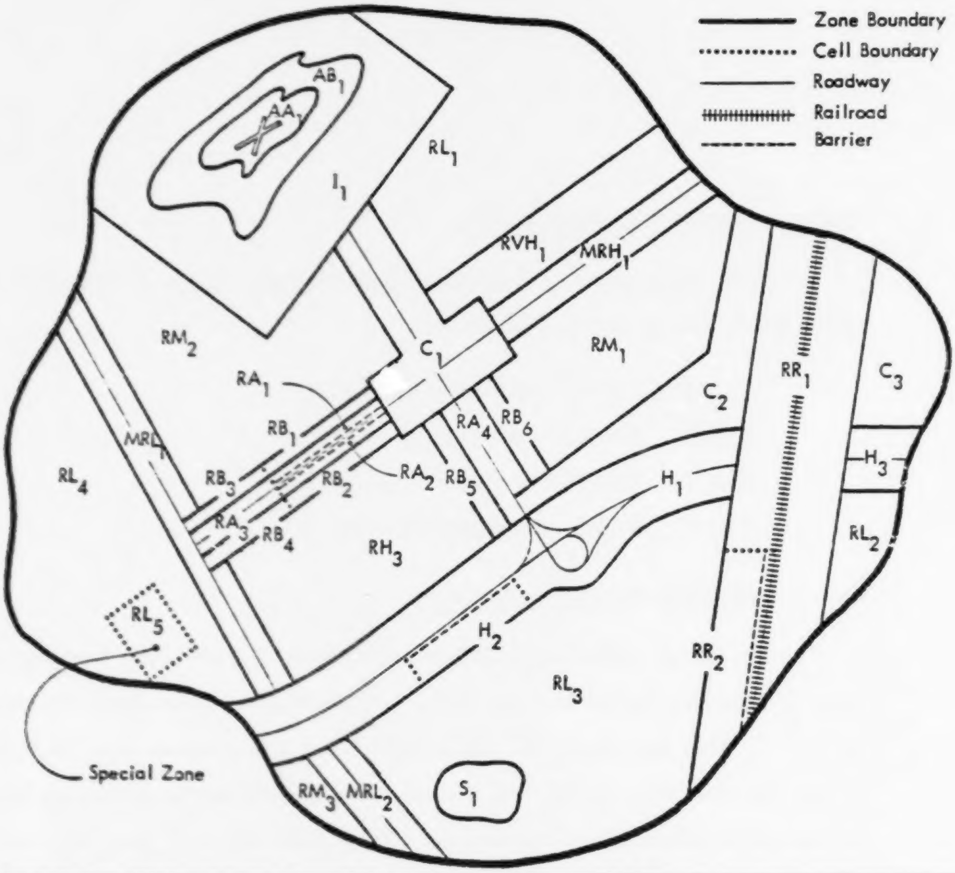
3.3.1 Divide Community Into Cells

In the acoustical and attitudinal surveys, the community was divided into many different noise zones, each zone representing an acoustically homogeneous area.[1, 2] Now each type of noise zone must be broken down into its individual discontiguous portions, called "cells" which are considered homogeneous in terms of land use and population density as well as noise. Referring to Figure 3-2, complete the following three steps:

Step 1. Define each discontiguous part of a noise zone as a separate cell. Each noise zone is originally composed of a number of separate parts; therefore consider each unconnected part as a separate cell.

Step 2. (a) Identify all locations in the community where barriers would be permitted for noise reduction purposes. Include all sections of well-traveled highways, major roadways, and railroad lines which have routes near residences and which would cause minimal aesthetic or commercial disruption if barriers were built alongside them. Potential barriers should only be identified for the side or sides of the roadway or track where residences are located.

(b) After identifying all potential barrier locations, define the area benefited by each barrier as a separate cell. With one exception, the benefited


Zone Boundary
Cell Boundary
Roadway
Railroad
Barrier
AB_1
AA_1
I_1
RL_1
RVH_1
MRH_1
RM_2
C_1
RM_1
RA_1
RB_1
MRL_1
RL_4
RB_3
RB_2
RA_2
RA_4
RB_6
RB_5
C_2
RR_1
C_3
H_3
H_1
RA_3
RB_4
RH_3
RL_2
RL_5
H_2
RR_2
RL_3
Special Zone
RM_3
MRL_2
S_1

KEY

Symbol	Noise Zone	No. of Cells	Symbol	Noise Zone	No. of Cells
AA	Airport Zone A	1	RA	Major Roadway A	4
AB	Airport Zone B	1	RB	Major Roadway B	6
C	Commercial	3	RVH	Very High Density Residential	1
H	Highway	3	RH	High Density Residential	1
I	Industrial	1	RM	Medium Density Residential	3
MRL	Minor Roadway (Low Volume)	2	RL	Low Density Residential	5
MRH	Minor Roadway (High Volume)	1	RR	Railroad	2
			S	Stationary Source	1

Note: In this figure, many cell boundaries are also defined by zone boundaries.

Figure 3-2. Illustrative Example of Community Noise Zones Divided Into Cells (subscripts indicate cell number). Note: Cell symbols are for this example only and are not designed to be consistent with the actual recommended symbols defined in References 2 and 26.

area may be assumed to extend perpendicularly from the outer edges of the barrier to the edge of the noise zone, as shown in Figure 3-2. The exception is that if a barrier is being considered for a Major Roadway zone, then the benefited area extends through Major Roadway Zone A to the edge of Major Roadway Zone B, as shown for cells RA_1, RB_1, RA_2, and RB_2 in Figure 3-2.

Step 3. If any "Special Zone" has been defined in the acoustical and attitudinal surveys, identify this area as a separate cell. In Figure 3-2, the Special Zone is wholly contained within the Low Density Residential Zone; therefore it is considered to be one of the Low Density Residential cells (RL_5).

Step 4. Identify any schools or hospitals in each noise zone in the community which should be considered as separate cells. This is done to account for the different sensitivity of these areas to noise from that found in the general noise zone (see Table 1-1 and Section 3.3.4).

Step 5. Overlay the cell division map on a census tract map (described in Section 3.3.2 below) and divide any of the cells which fall into two or more census tracts into separate cells so that no cell crosses census tract boundary lines.

After these steps have been completed, give each cell in each zone a number, as shown in Figure 3-2. These numbers will be used by the noise optimization model to identify the input data required for each cell as described in Table 4-1 in the next chapter. The preparation of this input data is discussed next.

3.3.2 Estimate Cell Populations

Estimate the populations of each cell for the target year by following the steps below. If the acoustical survey was performed in the community, Steps 1 through 5 may already have been completed. They are described here to clarify the succeeding steps.

Step 1. Collect Census Data and Estimate Census Tract Areas

The Bureau of the Census publishes a Block Statistics package for each urbanized area with cities of greater than 50,000 population (U.S. Bureau of the

Census, Census of Housing: 1970, Block Statistics, Report HC (3)). Each "package" contains a set of maps which show the boundaries of all census tracts for the area. Census tracts are small subdivisions into which large cities and metropolitan areas are divided for statistical purposes. Boundaries of these subdivisions are generally designed to achieve some uniformity of population characteristics, economic status, and living conditions. A typical census tract has a population of 3000 to 7000 and, for cities, an area of 1 to 2 square miles (2-1/2 to 5 square kilometers. Note: The primary measurement units in this section will be English, since census maps are marked in English dimensions). Obtain the Block Statistics package for the urbanized area which includes the community under consideration. One source is: Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

The census tract map or maps which include the community under consideration can be found using an index which accompanies the Block Statistics package. Estimate the area from each census tract which is wholly or partially within the community's boundaries using the appropriate maps.

In the case of Alexandria, Virginia, the desired census data are contained in "Washington, D.C. - Md. - Va. Urbanized Area Block Statistics," (Report HC (3)-44). The index to the detailed maps in this statistics package, illustrated in Figure 3-3, shows that Map 18 includes the entire town of Alexandria. A section of Map 18 is shown in Figure 3-4. The area of each census tract can be estimated by applying simple geometric techniques as shown in Figure 3-4. As shown in the figure, the area of census tract 2006 is approximately 0.9 square miles (2.3 square km).

Step 2. Find the Population of Each Census Tract

The 1970 population of each census tract is supplied in the Block Statistics volume accompanying the statistics package. If they are known, values for more recent years can be substituted to allow use of more accurate estimates of the impacted population. As shown in Figure 3-5, according to the 1970 census data, the population of tract 2006 illustrated is 5,050.

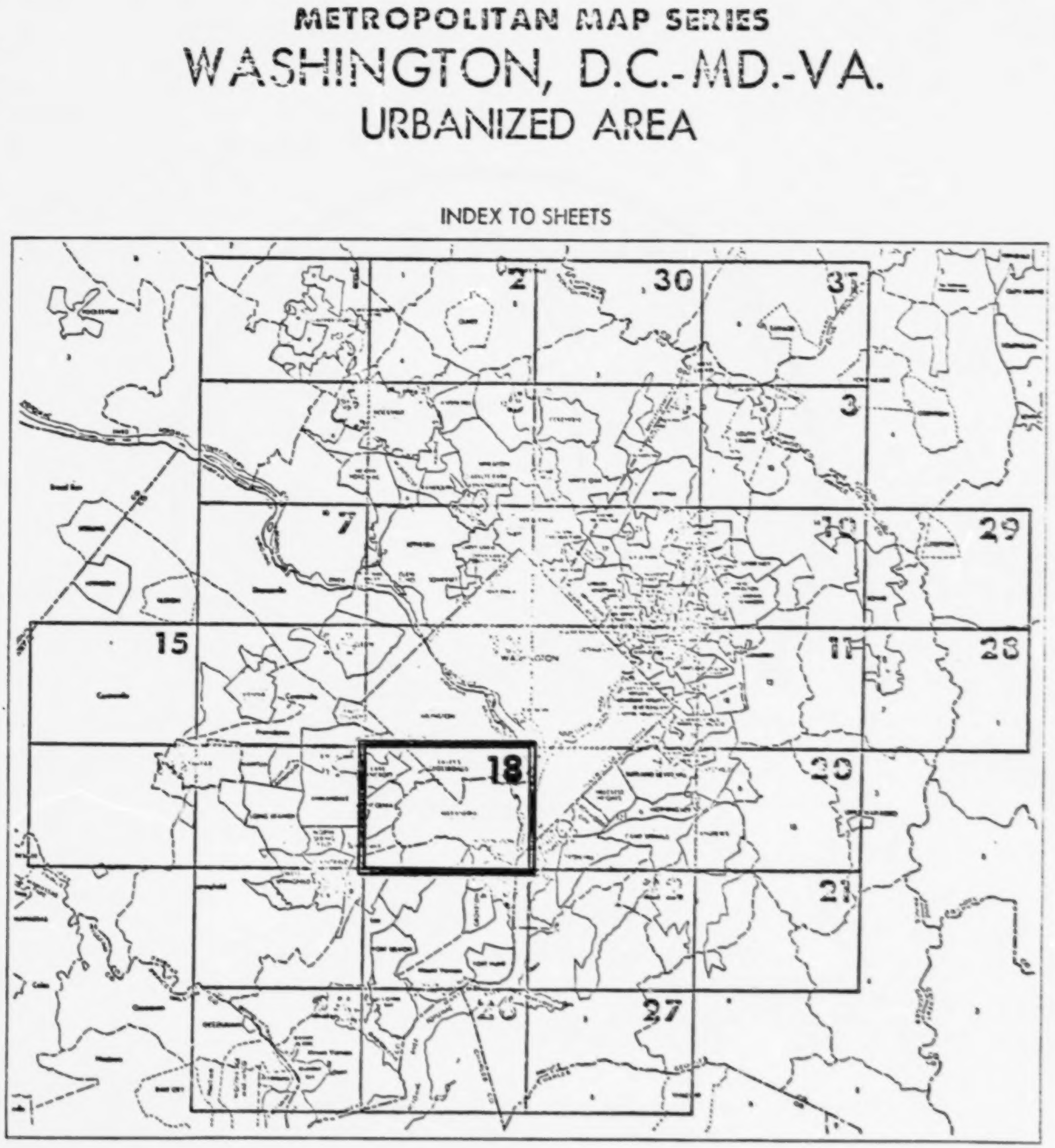
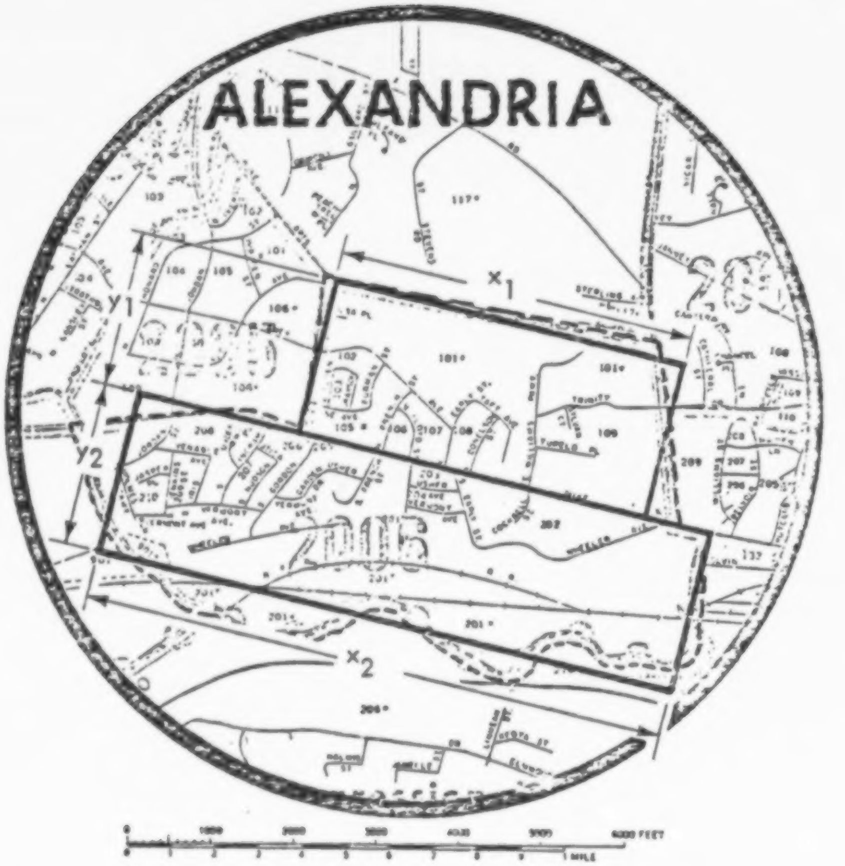

METROPOLITAN MAP SERIES
WASHINGTON, D.C.-MD.-VA.
URBANIZED AREA
INDEX TO SHEETS
1
2
30
31
3
7
10
29
15
11
28
18
20
22
21
26
27

Figure 3-3. Index to Census Map Sheets for the Washington, D.C. - Md. - Va. Urbanized Area


ALEXANDRIA
x1
y1
x2
y2
2006
0
1000
2000
3000
4000
5000
6000 FEET
1 MILE

Area of Census Tract # 2006

$A \simeq x_1 \cdot y_1 + x_2 \cdot y_2 = .9$ square miles (2.3 square km)

Figure 3-4. Section of Alexandria, Virginia Showing Computation of Approximate Area of a Typical Census Tract

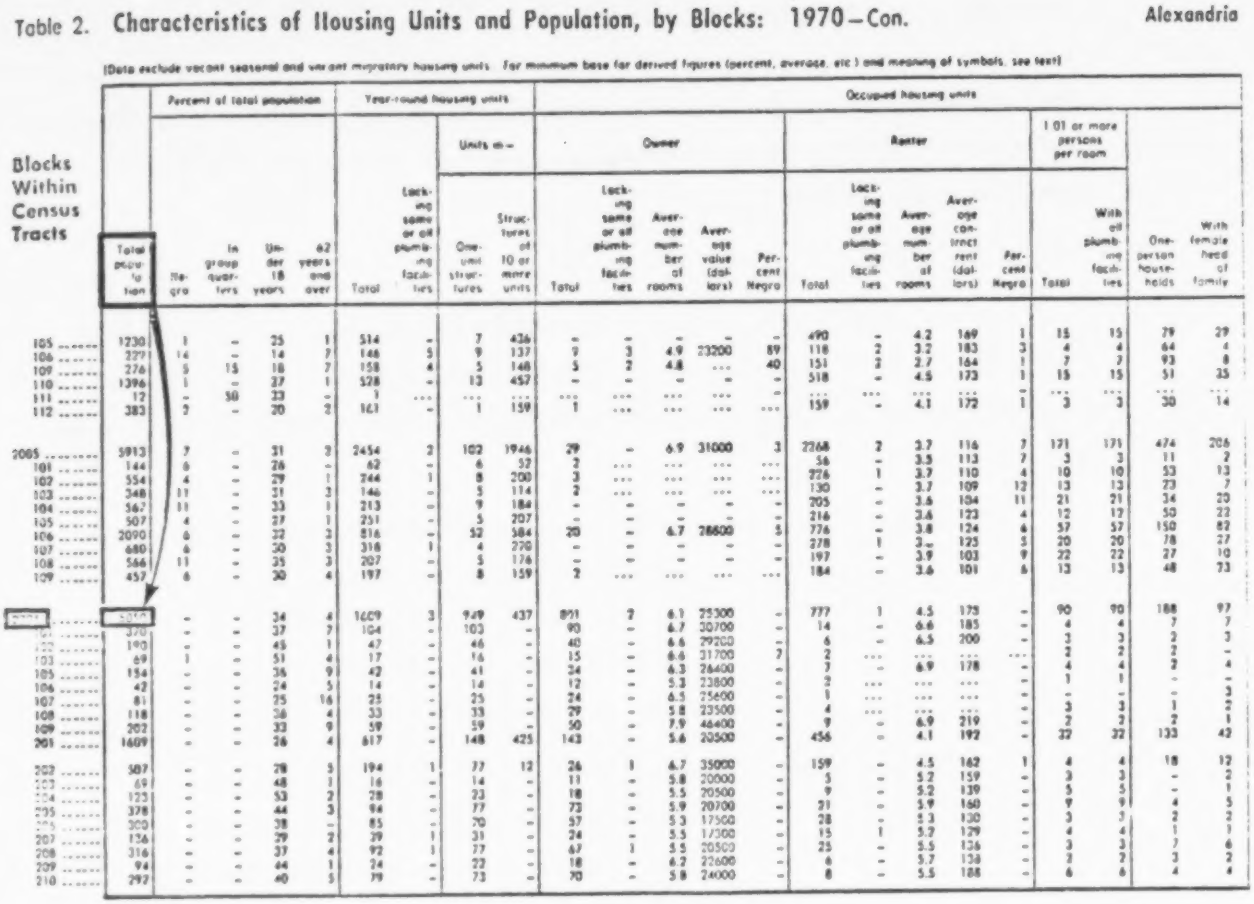


Table 2. Characteristics of Housing Units and Population, by Blocks: 1970—Con.

Alexandria

[Data exclude vacant seasonal and vacant migratory housing units. For minimum base for derived figures (percent, average, etc.) and meaning of symbols, see text]

Blocks Within Census Tracts	Total population	Percent of total population				Year-round housing units				Occupied housing units													
								Units in—		Owner					Renter					1.01 or more persons per room			
		Negro	In group quarters	Under 18 years	62 years and over	Total	Lacking some or all plumbing facilities	One-unit structures	Structures of 10 or more units	Total	Lacking some or all plumbing facilities	Average number of rooms	Average value (dollars)	Percent Negro	Total	Lacking some or all plumbing facilities	Average number of rooms	Average contract rent (dollars)	Percent Negro	Total	With all plumbing facilities	One-person households	With female head of family
105	1230	1	–	25	1	514	–	7	436	–	–	–	–	–	490	–	4.2	169	1	15	15	79	29
106	227	14	–	14	7	146	5	9	137	9	3	4.9	23200	89	118	2	3.2	183	3	4	4	64	4
109	276	5	15	18	7	158	4	5	148	5	2	4.8	...	40	151	2	2.7	164	1	7	7	93	8
110	1396	1	–	27	1	528	–	13	457	–	–	–	–	–	518	–	4.5	173	1	15	15	51	35
111	12	–	50	33	–	1	...	...	...	...	...	...	...	–	...	...	...	...	–	...	...	...	...
112	383	2	–	20	2	161	–	1	159	1	...	...	...	...	159	–	4.1	172	1	3	3	30	14
2005	5913	7	–	31	2	2454	2	102	1946	29	–	6.9	31000	3	2268	2	3.7	116	7	171	171	474	206
101	144	6	–	26	–	62	–	6	52	2	...	...	...	...	56	–	3.5	113	7	3	3	11	2
102	554	4	–	29	1	244	1	8	200	3	...	...	...	...	226	1	3.7	110	4	10	10	53	13
103	348	11	–	31	3	146	–	5	114	2	...	...	...	...	130	–	3.7	109	12	13	13	23	7
104	567	11	–	33	1	213	–	9	184	–	–	–	–	–	205	–	3.6	104	11	21	21	34	20
105	507	4	–	27	1	251	–	5	207	–	–	–	–	–	216	–	3.6	123	4	12	17	50	22
106	2090	6	–	32	3	816	–	52	584	20	–	6.7	28600	5	776	–	3.8	124	6	57	57	150	82
107	680	6	–	30	3	318	1	4	270	–	–	–	–	–	278	1	[illegible]	125	5	20	20	78	27
108	566	11	–	35	3	207	–	5	176	–	–	–	–	–	197	–	3.9	103	9	22	22	27	10
109	457	6	–	30	4	197	–	8	159	2	...	...	...	...	184	–	3.6	101	6	13	13	48	73
[illegible]	[illegible]	–	–	34	4	1609	3	949	437	891	2	6.1	25300	–	777	1	4.5	175	–	90	90	188	97
[illegible]	370	–	–	37	7	104	–	103	–	90	–	6.7	30700	–	14	–	6.6	185	–	4	4	7	7
[illegible]	190	–	–	45	1	47	–	46	–	40	–	6.6	29200	–	6	–	6.5	200	–	3	3	2	3
103	69	1	–	51	4	17	–	16	–	15	–	6.6	31700	7	2	...	...	...	...	2	2	2	–
105	154	–	–	36	9	42	–	41	–	34	–	6.3	26400	–	7	–	6.9	178	–	4	4	2	4
106	42	–	–	24	5	14	–	14	–	12	–	5.3	23800	–	2	...	...	...	–	1	1	–	–
107	81	–	–	25	16	25	–	25	–	24	–	6.5	25600	–	1	...	...	...	–	–	–	–	3
108	118	–	–	36	4	33	–	33	–	29	–	5.8	23500	–	4	...	...	...	–	3	3	1	2
109	202	–	–	33	9	59	–	59	–	50	–	7.9	46400	–	9	–	6.9	219	–	2	2	2	1
201	1609	–	–	26	4	617	–	148	425	143	–	5.6	20500	–	456	–	4.1	192	–	22	22	133	42
202	507	–	–	28	5	194	1	77	12	26	1	6.7	35000	–	159	–	4.5	162	1	4	4	18	12
203	69	–	–	48	1	16	–	14	–	11	–	5.8	20000	–	5	–	5.2	159	–	3	3	–	2
204	123	–	–	53	2	28	–	23	–	18	–	5.5	20500	–	9	–	5.2	139	–	5	5	–	1
205	378	–	–	44	3	94	–	77	–	73	–	5.9	20700	–	21	–	5.9	160	–	9	9	4	5
[illegible]	300	–	–	38	–	85	–	70	–	57	–	5.3	17500	–	28	–	5.3	130	–	3	3	2	2
207	136	–	–	29	2	39	1	31	–	24	–	5.5	17300	–	15	1	5.2	129	–	4	4	1	1
208	316	–	–	37	4	92	1	77	–	67	1	5.5	20500	–	25	–	5.5	136	–	3	3	7	6
209	94	–	–	44	1	24	–	22	–	18	–	6.2	22600	–	6	–	5.7	138	–	2	2	3	2
210	292	–	–	40	5	79	–	73	–	70	–	5.8	24000	–	8	–	5.5	188	–	6	6	4	4

Figure 3-5. Excerpt from U.S. Bureau of the Census 1970 Block Statistics for Alexandria, Va. Showing Total Population of a Sample Tract

Step 3. Computer the Average Population Density for Each Tract

Simply divide the population figures for each tract found in Step 2 by the associated area values estimated in Step 1. Thus, for the preceding example, the population density of sample tract 2006 is $5050 \div 0.9 = 5610$ people per square mile (or 2170 people per square kilometer). Note that this population density is intentionally based on the entire census tract area, including the area occupied by streets or other nonresidential land.

Step 4. Estimate the Land Area of Each Cell

In order to find the population contained within each cell of a given type of noise zone, its area must be estimated. This is accomplished in the following ways depending on the type of noise zone the cell lies in. It will be helpful at this point to refer to Figure 3-2.

Highway Noise Zone Cells – Multiply the length of each highway noise zone segment in each census tract by twice the zone width. (The zone width is measured from the center of the roadway.) For those highways which form tract boundaries, multiply each segment by only one zone width.

Major and Minor Roadway Noise Zone Cells – Multiply the length of each noise zone segment in each tract by twice the zone width. Note that, for major roadways with over 36,000 Average Daily Traffic, the area of a second zone (Major Roadway Zone) also must be computed. Again, use only a single roadway width if the road forms a tract boundary.

Railroad Noise Zone Cells – Multiply the length of the railroad line in each tract by twice the zone width.

Residential, Commercial or Industrial, Airport, and Stationary Source Noise Zone Cells – At this point, subtract the highway, roadway and railroad cell areas from the total tract area to obtain the combined area of the remaining residential, commercial or industrial, airport (A + B) and stationary source noise zone cells. Estimate the area of each of these remaining individual cells for each noise zone type using the previously established cell boundaries.

Step 5. Compute the Resident Population of Each Cell and Noise Zone

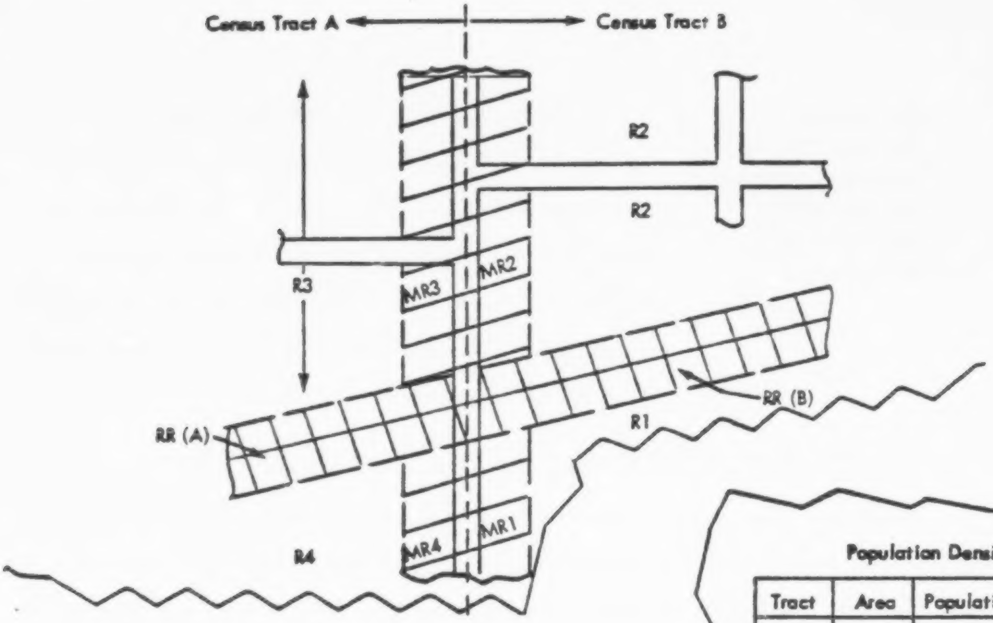
To compute the resident population of each cell, multiply the cell area (in square miles) by the density (per square mile) for the corresponding census tract which contains the cell. To obtain the total resident population for each noise zone, add the populations of all the cells contained in that zone. See Figure 3-6 for an illustration of this process.

Example

For the example based on a population density of 5,610 people per square mile (2,170 people per square kilometer), the hypothetical results for all the cells in census tract 2006 are as follows:

Noise Zone	Cell	Area m^2	Area (km^2)	Census Track Density People/mi^2	Population by Cell
Major Roadway A	RA_1	0.06	(.16)	5,610	337
Major Roadway B	RB_1	0.06	(.16)		337
High Volume Minor Roadway	MRH_1	0.01	(.026)		56
Railroad	RR_1	0.04	(.10)		224
Industrial	I_1	0.30	(.78)		1,683
Medium Density Residential	RM_1	0.43	(1.11)	5,610	2,413
Total		0.90	(2.34)		5,050

The results, as above, would be summed over all census tracts to obtain resident population totals for each type of noise zone.


Census Tract A
Census Tract B
R2
R2
R3
MR3
MR2
RR (B)
RR (A)
R1
MR4
MR1
R4

Population Density by Tract

Tract	Area	Population	Density
A	S_A	P_A	$\rho_A = P_A/S_A$
B	S_B	P_B	$\rho_B = P_B/S_B$

Zone	Cell	Area(s)	Census Tract	Density	Population	
					By Cell	By Zone
MR	1 2	S_{MR1} S_{MR2}	A ↓	ρ_A ↓	$S_{MR1} \cdot \rho_A$ $S_{MR2} \cdot \rho_A$	$\sum$ = Total Population for Zone MR
RR	RR 1 RR 2	$S_{RR\,1}$ $S_{RR\,2}$	A B	ρ_A ρ_B	$S_{RR\,1} \cdot \rho_A$ $S_{RR\,2} \cdot \rho_B$	$\sum$ = Total Population for Zone RR
R ↓	R1 R2 R3 R4 . .	S_{R1} S_{R2} S_{R3} S_{R4} . .	B ↓ A ↓ . .	ρ_B ↓ ρ_A ↓ . .	$S_{R1} \cdot \rho_B$ $S_{R2} \cdot \rho_B$ $S_{R3} \cdot \rho_A$ $S_{R4} \cdot \rho_A$ . .	$\sum$ = Total Population for Noise Zone R

Figure 3-6. Estimation of Individual Cell Populations in Each Type of Noise Zone

Step 6. Separate Cells into Residential and Nonresidential Categories

Examine the map of noise zones and cells which you have drawn and, comparing it with a land use map of the community, compile two lists:

1. A list of all cells which are primarily residential in land use.
2. A list of all cells which are primarily nonresidential in land use (i.e., this list includes all cells not in list 1 above).

In the example in Step 5, let us hypothesize that cells RB_1, MRH_1, and RM_1 were residential and that cells RA_1, I_1, and RR_1 were nonresidential.

Step 7. Compute the Daytime and Nighttime Population of Each Cell

Estimate the actual population of each cell for the daytime and nighttime separately by using the following expressions:

Residential:

$$PD_{r_i} = .6\,(R_i) + .1\,(F_{r_i} \cdot PNR_T)$$

$$PN_{r_i} = .99\,(R_i) + .01\,(F_{r_i} \cdot PNR_T)$$

Nonresidential:

$$PD_{nr_i} = .9\,(R_i) + .4\,(F_{nr_i} \cdot PR_T)$$

$$PN_{nr_i} = .99\,(R_i) + .01\,(F_{nr_i} \cdot PR_T)$$

where:

PD_{r_i}	is the daytime population for the i^{th} residential cell
PN_{r_i}	is the nighttime population for the i^{th} residential cell
PD_{nr_i}	is the daytime population for the i^{th} nonresidential cell
PN_{nr_i}	is the nighttime population for the i^{th} nonresidential cell

and,

R_i is the population for the i^{th} cell in a given tract (either residential or nonresidential) obtained in Step 5.

F_{r_i} is the fraction of the total residential land area of the i^{th} residential cell

F_{nr_i} is the fraction of the nonresidential land area of the i^{th} nonresidential cell

PNR_T is the total nonresidential population in the community under consideration

P_{RT} is the total residential population in the community.

Computer the total population for residential and nonresidential areas for use in the expressions above. Also compute the total land area for residential and nonresidential areas. Based on the preceding example, this would be done as follows (Note - English units used for illustration):

Total Residential Population - 337 + 56 + 2413 = 2806
Total Nonresidential Population - 337 + 1683 + 224 = 2244

Toral Residential Land Area - .06 + .01 + .43 = 0.5 sq. miles
Total Nonresidential Land Area - .06 + .3 + .04 = .4 sq miles

Now, assign each cell the fraction of the total residential or nonresidential area it contributes, as follows:

For Residential Cells		F_{r_i}
RB_1	$- .06 \div 0.5 =$	0.12
MRH_1	$- .01 \div 0.5 =$	0.02
RM_1	$- .43 \div 0.5 =$	0.86
		1.00

For Nonresidential Cells		F_{nr_i}
RA_1	$- .06 \div 0.4 =$	0.15
I_1	$- 0.3 \div 0.4 =$	0.75
RR_1	$- .04 \div 0.4 =$	0.1
		1.00

Applying the population formulae to our continuing example, we have

Residential Cells:

Cell	Daytime	Nighttime
RB_1	.6 (337) + .1 (.12 · 2244) = 229	.99 (337) + .01 (.12 · 2244) = 336
MRH_1	.6 (56) + .1 (.02 · 2244) = 38	.99 (56) + .01 (.02 · 2244) = 56
RM_1	.6 (2413) + .1 (.86 · 2244) = 1641	.99 (2413) + .01 (.86 · 2244) = 2408
Nonresidential Cells:		
RA_1	.9 (337) + .4 (.15 · 2806) = 472	.99 (337) + .01 (.15 · 2806) = 338
I_1	.9 (1683) + .4 (.75 · 2806) = 2356	.99 (1683) + .01 (.75 · 2806) = 1687
RR_1	.9 (224) + .4 (.1 · 2806) = 314	.99 (224) + .01 (.1 · 2806) = 225

Do not be concerned that each cell will be overrepresented with respect to its population; the optimization model considers the day and night cells for the time period for which each is defined, 15/24 of the day, and 9/24 of the day, respectively. The Noizop computer program does this automatically.

To gain further understanding of the above procedure, consider the following. The sum of the resident populations of each cell (from the census tracts) is 5050. Additional sums from the preceding chart are as follows:

	Daytime	Nighttime
Residential	1908	2800
Nonresidential	3142	2250
Totals	5050	5050

All we have done is to take the actual population of the community and redistribute the population according to estimates of locational and activity cycles of people.[8] This redistribution was performed separately for day and night.

For those separate cells identified as schools or hospitals, estimate the daytime and nighttime populations from school enrollment and staff and patient counts. Nighttime populations for schools are assumed to be zero.

Step 8. Adjust Populations for Target Year

Estimate the average annual growth rate r, in percent, for the community expected between now and the target year based on recent community population trends. Label the number of years between now and the target year "y." Compute the expected populations in the target year by using the following expression:

$$P_{exp} = P_{curr} (1 + r/100)^y$$

where:

P_{exp} is the expected population, and

P_{curr} is the current population.

If the community had an average annual population growth rate of 4 percent, then, assuming a target year 5 years in the future, the target year population for cell RB_1 would be

$$\text{Daytime } P_{exp} = 229 (1 + .04)^5 = 279$$

$$\text{Nighttime } P_{exp} = 336 (1 + .04)^5 = 409$$

3.3.3 Establish Baseline Noise Levels

The noise levels from each major noise source in each of the cells must now be prepared for input into Noizop. These noise levels are those which would be expected in the target year if no abatement measures were implemented. If there is no information to indicate the contrary, assume that the noise levels measured in the acoustical survey are the same as those in the target year. If it is desired to modify the baseline noise levels to reflect those in the target year, consult Section 2.8 of the Noizop User's Guide (data factoring facility).[3]

The computerized data reduction analysis of the acoustical survey provides two important outputs which must be input into Noizop: (1) the day and night sound levels (L_d and L_n) of each source; and (2) the attitudinal adjustments (if any) to be applied to these levels. The first output, average noise levels, was illustrated earlier in Figure 2-4. Using the data collected from the procedure described in Section 2.4, assign these zone-averaged levels to each cell in the noise zone. As a result, all cells in a given zone will have the same noise levels. The only difference between cells in a zone will be their population, land use, and land area (used to estimate building floor area for sound insulation). The mechanics of physically entering the noise levels into the computer model is described in the Noizop User's Guide.[3]

. There is one exception to this procedure of assigning noise levels to cells. If a Special Noise Zone has been defined in the acoustical survey, separate noise level information will be available for that zone, and should be used instead of the zone-wide average levels. Each Special Noise Zone is a separate cell as far as the strategy analysis is concerned and therefore, in this case, the noise levels defined for Noizop for this cell will be different than other cells in the same zone.

3.3.4 Apply "Attitude Adjustment Factors" to Baseline Noise Levels for Each Source

The second output of the acoustical data reduction involves attitudinal adjustments to the source noise levels.[26] When necessary, attitudinal adjustments are applied to the noise levels of those sources which cause particularly strong attitudinal responses in the community. This ensures that noise sources which are of particular concern in the community receive extra attention in the set of noise abatement measures ultimately chosen by the optimization model. The attitudinal adjustments are based on the correlation between community noise levels and attitudes, using data obtained in the attitudinal and acoustical surveys.

It is important to note that the output of adjustment factors from the computerized data reduction of the acoustical survey will be available only if the attitudinal data was available at the time the computer processing of the acoustical data was performed.[26] If these adjustment factors are not available, the following general procedure (which parallels the computer calculations) should be followed. The procedure develops "attitudinal adjustment factors" from a simple semi-empirical analysis of the deviation between noise level versus annoyance relationships for specific sources and the same relationship for all sources combined.

Step 1. Assemble Acoustical and Attitudinal Data

The data to be assembled in this step are the noise levels (L_{dn}) for each source in each noise zone and the percent of people who reported being highly annoyed or above for each source in each zone. These data were previously acquired in Sections 2.3 and 2.4 of this manual.

Step 2. Determine the Relationship Between the Acoustical and Attitudinal Data

Compute a linear regression line for percent annoyed versus day-night sound level using each individual data point collected in Step 1. An illustration of a plot of such data is shown in Figure 3-7 where all sources are plotted but motorcycles and railroads are given different symbols for this example.

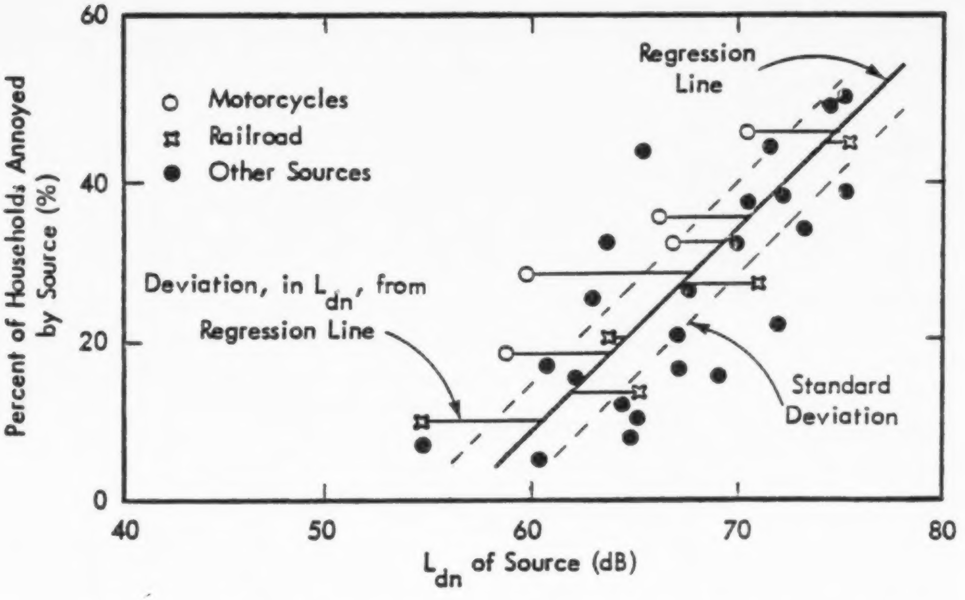


Figure 3-7. Hypothetical Plot of Acoustical and Attitudinal Data for Calculation of Attitudinal Adjustment Factors (also shown is the resultant regression line)

If the slope of the resultant regression line is greater than 10., a new regression line should be calculated with the slope forced to 10. . If the slope of the resultant regression line is less than 2., a new regression line should be calculated with the slope forced to 2. . Figure 3-8 presents a flow of the computer output that results from this procedure. In the example in Figure 3-8(a), the slope was initially too small and forced to be equal to 2.

Next, calculate the horizontal distance (or deviation in L_{dn}) from each data point to the regression line. Compute the standard deviation of these distances for all data points together (bottom of Figure 3-8(a)). Also, for each source separately, calculate the arithmetic average of these deviations from the regression line. See Figure 3-8(b).

a)
```
FIRST LINEAR REGRESSION

NUMBER OF ZONES:   6
NUMBER OF SOURCES:    15
SLOPE:            1.12
INTERCEPT:    -50.41
CORRELATION COEFFICIENT:       .305
NUMBER OF DATA POINTS:   78


FIRST LINEAR REGRESSION -


SLOPE FORCED
SLOPE:            2.00
INTERCEPT:    -96.36



STD. DEV.:     8.690
```

b)
```
SOURCE NO.    AVERAGE DISTANCE    CRITERIA INDICATOR

    1.              4.57                  0
    2.              5.46                  0
    3.               .00                  0
    4.             -2.81                  0
    5.             -5.24                  0
    6.              2.02                  0
    7.              4.47                  0
    8.              -.06                  0
    9.              4.04                  0
   10.              6.12                  0
   11.            -13.47                  1
   12.               .00                  0
   13.             -1.72                  0
   14.              5.24                  0
   15.              3.46                  0
   16.              4.67                  0
   17.            -12.50                  1
   18.               .30                  0
   19.               .00                  0
   20.               .00                  0
```

c)
```
SECOND LINEAR REGRESSION -

NUMBER OF ZONES:   6
NUMBER OF SOURCES:    13
SLOPE:             .53
INTERCEPT:    -22.66
CORRELATION COEFFICIENT:       .207
NUMBER OF DATA POINTS:   67



SECOND LINEAR REGRESSION -


SLOPE FORCED
SLOPE:            2.00
INTERCEPT:   -132.64



STD. DEV.:     6.966
```

d)
```
SOURCE    CRITERION    AVERAGE    STANDARD DEVIATION    NUMBER     SIGNIFICANCE
NUMBER    INDICATOR    DISTANCE     OF DISTANCES       OF POINTS    CRITERIA

  1.          0           2.43          2.96               5          2.32
  2.          0           3.32          2.67               4          2.03
  3.          0            .00           .00               0           .00
  4.          0          -4.95          6.85               6          3.55
  5.          0          -7.35         10.60               6          5.65
  6.          0           -.12          3.07               5          2.07
  7.          0           2.33         13.11               4          6.48
  8.          0          -2.20          4.10               5          2.59
  9.          0           1.90          6.47               6          3.56
 10.          0           3.94          2.48               6          1.70
 11.          1         -15.61          8.21               6          4.43
 12.          0            .00           .00               0           .00
 13.          0          -3.05          9.38               5          5.49
 14.          0           3.10          2.47               5          1.79
 15.          0           1.34          5.71               5          4.00
 16.          0           2.53          4.57               5          2.84
 17.          1         -14.64          5.14               5          3.14
 18.          0            .00           .00               0           .00
 19.          0            .00           .00               0           .00
 20.          0            .00           .00               0           .00
```

Figure 3-8. Example Flow of Computer Output for Calculating Attitudinal Adjustment Factors. (a) Results of initial linear regression, (b) Tabulation of distances (or deviations) from regression line for each source, (c) Results of second linear regression using qualifying sources, (d) Tabulation of parameters used in the final computation of the factors. See Figure 3-9 for a list of the final attitudinal adjustment factors for this example.

Compare this average deviation for each source to the standard deviation for all data points together. Let this latter standard deviation value act as a criteria limit for the average deviation from the regression line. Note which sources have an average deviation, either positive or negative, which is greater than this standard deviation criterion. The "criterion indicator" in Figure 3-8(b) indicates (with a "1") which of these hypothetical sources exceeded this criteria. In Figure 3-7, the motorcycle source would be so noted since the average deviation for these data points is clearly larger than the one standard deviation indicated. The railroad source would not be so noted since the average deviation for that source is clearly within the one standard deviation criterion limit.

Step 3. Compute Refined Relationship Between Source Noise Level and Annoyance

Compute a new regression line using the data points from the noise sources which have average deviations less than the one standard deviation criteria calculated in Step 2. These will be identified as "qualifying" data points.

Again, verify that the slope of the new regression line is between 2. and 10. (See Figure 3-8(c)). This new line is calculated to ensure that the relationship between percent annoyed and L_{dn} is based on noise sources having average or standard annoyance responses.

Recalculate the standard deviation (call it σ_T) of the difference, in L_{dn}, between the "qualifying" data points that formed the new regression line and this new regression line. Also recalculate the arithmetic average deviation, in L_{dn}, from the regression line to the data points for each noise source separately. Also, for each source separately, calculate the standard deviation of these differences between each data point and the regression line. To summarize, at this point, we should have the following information.

1. Standard deviation (σ_T) of the differences in L_{dn} between the qualifying points and the new regression line, and the total number (N) of data points that comprised the regression line. In Figure 3-8(c), σ_T equals 6.964 dB and N equals 67.

2. A tabulation of the standard deviations (call them σ_i) of the differences, in L_{dn}, between each data point and the new regression line for each source separately (column 4 of Figure 3-8(d)) and the number (n_i) of such data points for each source (column 5 of Figure 3-8(d)). Note that $\sum_i n_i$ will always be equal to or greater than N.

3. A tabulation of the arithmetic average difference, in L_{dn}, between each data point and the new regression line (column 3 of Figure 3-8(d)).

Step 4. Compute Significance Criteria

Using the data in items 1. and 2. in Step 3, compute the following significance criteria (SC_i) for each noise source (column 5 of Figure 3-8(d)).[9]

$$SC_i = 1.282 \sqrt{\frac{\sigma_T^2}{N} + \frac{\sigma_i^2}{n_i}}$$

This expression tests for a significance (at the 10 percent level) in the difference between two means. If the average difference for a source (item 3, Step 3) is greater in absolute magnitude than the significance criteria for that source, then the average difference becomes the nominal attitudinal adjustment factor. This factor should be limited to a maximum value of +10 dB. Figure 3-9 illustrates the final adjustment factors using the example of Figure 3-8. Note that the source numbers of Figures 3-8 and 3-9 correspond to the sources listed in Figure 2-4 from the acoustical survey. The adjustment factors listed in Figure 3-9 are intentionally shown exactly as they were computed for the example. In practice, it would often be prudent to round these adjustment factors, at least to the nearest decibel, if not to the nearest 5 decibels.

There are three situations for which no attitudinal adjustment factors should be calculated:

1. There are less than five noise sources overall.
2. Four or more sources were noted as failing the initial criteria in the last paragraph of Step 2.

```
            ATTITUDINAL ADJUSTMENT FACTORS

       (TO BE SUBTRACTED FROM SOURCE LEVELS)

          SOURCE NO.        ADJUSTMENT, DB

              1.                 2.4

              2.                 3.3

              3.                  .0

              4.                -4.9

              5.                -7.4

              6.                  .0

              7.                  .0

              8.                  .0

              9.                  .0

             10.                 4.0

             11.               -10.0

             12.                  .0

             13.                  .0

             14.                 3.1

             15.                  .0

             16.                  .0

             17.               -10.0

             18.                  .0

             19.                  .0

             20.                  .0
```

Figure 3-9. Example Computer Output Presenting the Final Attitudinal Adjustment Factors.

3. There are less than 10 sources overall and three failed the initial criteria in the last paragraph of Step 2.

The final attitudinal adjustment factors should be input into Noizop (see Appendix A.2.1). The optimization analysis will then be performed on the basis of noise levels corrected with these adjustment factors to more accurately reflect community attitudes toward specific noise sources.

3.3.5 Prepare Land Use Information

For each cell, determine its primary land use from the list of land uses given in Table 3-6. As shown in the table, each land use has an associated code. Each cell is assigned the appropriate code, and this information is provided to Noizop along with the other cell data described in Section 3.3.

Table 3-6

Land Use Codes to be Used for Each Cell

Primary Land Use in the Cell	Internal Land Use Code in Noizop
Low Density Residential	1
High Density Residential	4
Commercial	5
Industrial	8
Schools	10
Hospitals and Nursing Homes	12

To determine which code should be assigned to a cell, find the proportion of the cell devoted to each land use. Choose the land use to which the majority of the cell is devoted. The only two differences between land uses, as far as the optimization model is concerned, are (1) the noise levels at which adverse community response is assumed to begin; and (2) the levels at which it reaches 100 percent. These noise levels were shown for each land use category in Table 1-1, page 1-7. The 100 percent response levels are, in all cases, assumed to be 20 dB above the zero response levels. Different maximum and minimum impact levels are defined for both daytime and nighttime hours.

After a land use code has been assigned to each cell, estimate the floor area of the buildings in each cell. This information must be obtained so that estimates can be made later of the cost of relocating the businesses and people in a cell where the impact from noise is very great.

3.4 Estimate Costs and Noise Reductions of Alternatives

In this section, you will estimate the costs and noise reduction capability of the alternatives chosen for analysis previously in Section 3.1. Methods of making these estimates are described for each alternative. To proceed through this section, follow these five steps:

Step 1. Define the specific details of each selected alternative. (These defined measures are called "countermeasures.")

Step 2. Proceed to the discussion of each selected alternative in this section.

Step 3. Estimate the costs of each countermeasure.

Step 4. Estimate the noise reduction resulting from each countermeasure.

Step 5. Establish cost functions for each countermeasure by pairing the costs with associated noise reductions.

Once these five steps are completed, you will have enough data to operate the cost-effectiveness program Noizop. Each step is discussed briefly below.

Step 1. Define the Specific Details of Each Selected Alternative

A number of applicable alternatives were selected in Section 3.1. Now resolve the details of each as they would be applied to your community. For noise standards, for instance, select one or more possible regulation levels and decide whether these levels are to be in effect under typical maximum noise level operating conditions. Also, determine whether the costs involved in administering and enforcing the regulation will come entirely from municipal funds or whether federal or state assistance is available. For time restrictions, decide which time periods will be restricted. For a retrofit equipment standard, develop the specifications which must be met by replacement parts.

These definitions can be somewhat tentative and initially imprecise. However, they will become more specific as the discussion of costs and noise reduction capabilities of each alternative points out what further information is required. From now on, every specific alternative so defined will be called a "countermeasure." Note that there may be two countermeasures under one alternative if two noise sources are involved. For instance, if a time restriction alternative is recommended for both jet aircraft and domestic equipment, two different specifications will need to be drawn up defining the two different countermeasures. On the other hand, if the same noise standard is recommended for both automobiles and trucks, only one countermeasure needs to be defined since only one set of specifications is required. A more detailed discussion of how to define countermeasures is given in the Noizop User's Guide[3] and in Appendix A.

Step 2. Proceed to the Discussion of Each Selected Alternative in this Section

The costs and noise reduction capabilities of the 19 alternatives listed in Table 3-1, page 3-2, are discussed in separate sections below. For each recommended alternative, go to the appropriate section and follow the procedures described there.

Step 3. Estimate the Costs of Each Countermeasure

The cost of a measure is only defined to include all "primary" costs which are incurred, whether these are by the government, citizens, industry, or other groups. "Primary costs" are defined, for the purposes of this manual, as follows:

1. In cases where there is only one financial transaction, primary costs are those incurred by the paying party.
2. In cases where costs are passed on from one party to another, primary costs are those incurred by the party who cannot pass on the costs any further without substantial diminution of the costs.

Any revenues which may result from a noise abatement measure follow the same rules. As an example of a one-time financial transaction, consider the construction of a noise barrier alongside a highway; the government pays (i.e., a primary cost) to build the barrier. Construction workers involved in the project may spend their increased revenue from the government on items which lead to increased employment, industrial expansion, and more revenues for the local government; however, these are not primary costs or revenues as defined by the rules above, and therefore they are not considered in this manual. On the other hand, a vehicle regulation may cause increased manufacturing costs which are directly passed on to the consumer. The costs of the abatement measure are then the costs which the consumer has to pay.

Under the discussion of each alternative in succeeding sections, costs are first described, then noise reductions. Costs are identified as to whether they are incurred by local governments, by other parties, or both. For each countermeasure which is to be evaluated, first find the total cost of the countermeasure. This cost represents the entire cost to society, and is the main cost input for Noizop. Next, find the fraction of this cost which would be incurred by the local governments. This is a second cost input for Noizop.

A list of both types of cost components is given in Table 3-7, showing their symbolic notation and meaning as used in this manual. Table 3-8 shows which components are required to estimate costs for each alternative. Gather information on each of the components which are required for the alternatives selected for analysis. Table 3-9 provides default cost values for some components, which may be used only if local data are not available. These default values are strictly valid for 1977 only.

The relationship between the total societal cost of a countermeasure and its associated noise reduction is called a "cost function." Some cost functions only involve a single discrete step. For example, a barrier is either built or it isn't. In other cost functions, the costs increase monotonically and continuously as the desired noise reduction increases. For the step cost functions, only three numbers need to be determined: (1) the cost; (2) the fraction of the cost incurred by the city; and (3) the noise reduction. For the continuous cost function, a number of cost/noise reduction pairs must be defined. As many as seven segments of the cost curve may be defined; therefore, as many as eight pairs of cost/noise reduction values may be input to Noizop to define a continuous cost function. It is recommended that the user define as many segments as practical to accurately portray the real cost/noise reduction relationship. In practice, usually three to four segments (four to five cost/noise reduction pairs) are sufficient to define most continuous cost functions.

Table 3-7

Meaning and Symbols of Countermeasure Cost Components

Symbol	Meaning
A	Floor area of buildings in each noise reduction category (square meters)
B	Number of non-conforming buildings over 50 years old in areas to be zoned
C_A	Cost to operator of altering equipment (per piece)
C_B^*	Cost of barrier (per linear meter)
C_C^*	Cost to conform to code (per square meter)
C_D	Cost of demolition
C_E^*	Cost of employee (per month)
C_I^*	Cost to insulate (per square meter)
C_L	Cost to operator of additional labor and administration
C_M	Cost of media and materials
C_O	Additional cost of operating equipment (per piece)
C_R	Cost to relocate (per building)
C_S^*	Cost due to delays in schedule
C_T	Cost of training operators
D^*	Discount Factor
E	Number of employees in city
E_R	Reduction of employees (man-years)
F^*	Fuel savings (per square meter)
H	Number of households affected
L	Length of barrier (meters)
$M_{A/E}$	Number of man-months required for administration and enforcement (per year)
M_M	Number of man-months required for maintenance (per year)
P	Number of commercial properties affected
Q	Number of modified pieces of equipment
R	Annual municipal income and sales tax revenues
R_C	Change in revenues due to tax program
S_E	Sales lost due to elimination of operation
S_P	Net monthly sales for commercial properties acquired (12-month average)
S_R	Sales during restricted hours (per year)
S_S	Sales expected to shift to non-restricted hours (per year)
T	Property tax rate for each property class
U	Number of undeveloped lots in areas to be zoned
V_A	Average assessed value of property
$V_{L/P}$	Ratio of land value to property value
V_R^*	Property value reduction due to aircraft flyovers (per household)
W	Wholesale price index for industrial commodities
X	Consumer price index for home-ownership
Y	Remaining physical life of impacted buildings (years)

*Unit costs provided in this manual.

Table 3-8

Cost Components of Each Alternative

Alternative	Cost Components*
Operational Restrictions	
Noise Standard	$C_A, C_E, C_O, C_L, C_T, D, M_{A/E}, Q$
Operational Controls	$C_E, C_L, C_O, C_S, C_T, D, M_{A/E}, Q, W$
Area Restrictions	$C_E, C_O, D, M_{A/E}, Q$
Time Restrictions	$C_E, C_L, C_S, D, E, E_R, M_{A/E}, R, S_R, S_S, W$
Permits	$C_E, C_L, C_S, D, M_{A/E}, S_E$
Land Use Restrictions	
Barriers	$C_B, C_E, D, L, M_{A/E}, M_M, W$
Building Insulation	$A, C_E, C_I, D, F, M_{A/E}, X$
Compensation	$C_E, D, H, M_{A/E}, V_R, Y$
Population Relocation	$C_D, C_E, C_R, D, H, M_{A/E}, P, S_P, T, V_{L/P}, V_A$
Planning/Zoning	$V_A, B, C_E, C_R, D, M_{A/E}, T, U$
Building Codes	$A, C_C, C_E, D, F, M_{A/E}, X$
Tax Measures	
Tax Incentives	$C_E, D, M_{A/E}, R_C$
Tax Penalty	$C_A, C_E, D, M_{A/E}, Q, R_C$
New Product Regulations	
Noise Standard	$C_A, C_E, C_L, C_O, C_T, D, M_{A/E}, Q$
Labeling	$C_A, C_E, C_L, D, M_{A/E}, Q$
Equipment Standard	
Maintenance	$C_A, C_E, D, M_{A/E}, Q$
Retrofit	$C_A, C_E, D, M_{A/E}, Q$
Other Alternatives	
Education**	$C_E, C_M, D, M_{A/E}$
Complaint Mechanisms**	$C_E, D, M_{A/E}$

*Symbols defined in Table 3-7.

** Additional costs may be incurred depending on exact form of the alternative.

Table 3-9

Default Cost Values for Selected Cost Components

Symbol	Cost Component	Value (in 1977 Dollars)
C_B	Cost of barriers per linear meter	See Table 3-13 (p. 3-70)
C_C	Cost to conform to building code	See Table 3-18 (p. 3-86)
C_E	Cost of employee, per month	$2500
C_I	Cost of insulation	See Table 3-16 (p. 3-76)
C_S	Cost of delays in schedule	See Table 3-12 (p. 3-58)
D	Discount factor	See Table 3-10 (p. 3-46)
F	Fuel savings due to insulation	See Table 3-15 (p. 3-76)
V_R	Property value reduction due to frequent aircraft flyovers	5 to 20% of original property value[10]

Under the discussion of each alternative, it is indicated whether the cost function has discrete steps or is continuous. Barriers, building insulation, and stationary source noise reduction are examples of single step cost functions. Regulatory measures, whose effectiveness increases proportional to the strictness of the regulation, exemplify continuous cost functions. For step functions, merely find the cost of the countermeasure and the fraction incurred by the city according to the relationship provided. For continuous functions, estimate the costs and city fractions for three to four levels of strictness (cost function segments) for each countermeasure. For instance, estimate the costs of establishing an operational noise limit on trucks 1 year from now for regulatory levels of 83 dB, 80 dB, and 75 dB. Later, in Step 4, estimate the overall noise reduction to the fleet of trucks which would occur in the target year if these limits were established, and pair these values in Step 5, thereby defining a "continuous" cost function. The cost-effectiveness model will choose an optimal amount of money to spend on this measure by considering the relative costs and noise reduction capabilities of all countermeasures defined. If it chooses a cost which lies between the exact costs identified for a given countermeasure strictness – say, a cost that lies between the costs of an 83 dB noise limit and an 80 dB limit – then this implies that an intermediate limit should be established for the most cost-effective results.

Only one value of the cost fraction attributed to the city can be specified for each countermeasure; so if the city fraction is found to vary with the level of countermeasure strictness, use an average value of the fractions as the input to Noizop.

Costs incurred immediately are more significant than costs incurred in later years because of lost interest opportunity, which is the cost involved in the use of money. Some method must therefore be used to adjust cost figures on the basis of the year in which they occur. The process used in this manual is referred to as discounting. A representative discount rate of 10 percent is chosen for this manual.

The current value of money is called its present value (PV). Present value is the sum of anticipated future cash outflows (or inflows) discounted back to a chosen base date at the appropriate interest rate. Costs which occur during each year can be discounted using the factors in Table 3-10. For example, a $1000 expense incurred 5 years from now is considered to be equivalent to a $621 expense incurred today. Factors can be added for identical recurring costs; e.g., if administrative costs are $20 thousand per year for 5 years, the present value can be calculated as follows: ($20,000) x (1.000 + .909 + .826 + .751 + .683) = $83,380. Therefore, if the choice is between a one-time investment which costs $100 thousand during the first year and an option which costs $20 thousand per year for 5 years, the winner (based on cost only) becomes readily apparent with this simple but accurate analysis.

Table 3-10

Factors for Calculating Present Value of Costs Based on a 10 Percent Discount Rate[11]

Number of Years Until Cost is Incurred	Discount Factor*
0	1.000
1	.909
2	.826
3	.751
4	.683
5	.621
6	.564
7	.513
8	.467
9	.424
10	.386
11	.350
12	.319
13	.290
14	.263
15	.239
16	.218
17	.198
18	.180
19	.164
20	.149
25	.092
30	.057

* $PV(E) = \sum_{t=1}^{30} \frac{E_t}{(1+r)^t}$ where E = expenditure, 1978 as t=0, 1980 as t=2, etc., and r = discount rate (10 percent)

With the advent of electronic pocket calculators, the use of a mathematical formula may be more convenient. The present value, PV, of an expense, E, incurred t years from now is:

$$PV = \frac{E}{(1+r)^t}$$

where r is the discount rate (0.10 for 10 percent). If E_t is the expense in the t^{th} year, the present value of the sum sequence of yearly expenses is equal to:

$$PV = \sum_{t=0}^{N} \frac{E_t}{(1+r)^t}$$

where t starts with zero; i.e., current expenses are included at full value. If E_t is constant and equal to E (does not change for all years), then the formula for the sum of a geometric series simplifies computation:

$$PV = E \, \frac{1-q^{N+1}}{1-q}$$

where $q = \frac{1}{1+r}$. Again, because t is allowed to start at zero, E is incurred N+1 times.

In most cases, the annual cost of a given item, such as the cost of a new city noise enforcement officer, is incurred over many years. Using the present value analysis, any costs after about 30 years contribute a negligible amount to the total cost. Even if annual costs are incurred out to infinity, the total cost remains finite. To illustrate this concept, set N = ∞ in the equation just above and set the discount rate, r, equal to 10 percent. Then,

$$PV = E \cdot \left[\frac{1}{1 - \frac{1}{1+0.1}} \right] = E \cdot 11$$

In other words, the total cost of an item which costs the city E dollars every year is 11 times E. In the equations provided below, this factor of 11 is used for each cost component which is incurred annually. In addition to this factor, annual costs are also multiplied by a discount factor, D, corresponding to the number of years from now when the annual costs begin. These discount factors were listed earlier in Table 3-10.

Costs which are incurred only once, such as the cost of building a noise barrier, are also multiplied by a discount factor corresponding to the number of years from today when the cost occurs.

Some of the costs discussed in this manual (e.g., sound insulation, barriers) were thoroughly analyzed in previous studies. Therefore, it should be unnecessary for the city to redevelop detailed cost analyses of these particular cost elements. However, it will be necessary to adjust costs for the impact of inflation. This can be accomplished most directly by the use of consumer and wholesale price indices published monthly in the Federal Reserve Bulletin for various commodities. For example, suppose a 1972 study determined that a barrier 15 feet high costs \$50 (1972 dollars) per linear foot. The applicable wholesale price indices for industrial commodities are 117.9 for 1972 and 199.2 for 1977.[12] The estimated 1977 costs are derived by dividing the 1977 index by the 1972 index and multiplying the result by \$50: (199.2/117.9) x (\$50) = \$84.48 (1977 dollars) per linear foot.

The development of continuous cost functions implies that intermediate levels of strictness will be considered for each option category; e.g., an airport curfew can be imposed for various lengths of time, such as 11 p.m. to 6 a.m., midnight to 5 a.m., etc. Therefore, the development of cost estimates will not generally be so straightforward as to involve the calculation of only one cost for a given option. The cost for a curfew from midnight to 6 a.m. is not necessarily twice the cost of a midnight to 3 a.m. curfew.

Therefore, when data are available, it is advisable to analyze each level of strictness separately. Where simplifications are desired or required due to lack of data, however, linear approximations to cost functions can be considered adequate. To derive linear cost functions, it is first necessary to calculate the cost of the most extreme case under consideration; e.g., an 8-hour airport curfew. Then to determine the costs of intermediate options, assume that proportionate cost increases occur between the "do-nothing" case and the most extreme case. For this example, a 6-hour curfew would then be assumed to cost 25 percent less than the 8-hour curfew.

For the various countermeasures, there are both direct and indirect costs. Direct costs are the costs for labor and material devoted specifically to a given countermeasure. Indirect costs are the cost which cannot be consistently identified with a specific countermeasure. Such costs are joint in nature and can be apportioned to different countermeasures only by a rough approximation. Examples include administrative and enforcement costs incurred by local planning departments, noise abatement offices, building inspectors, legal personnel, police, etc.

For budgetary reasons, it is often desirable to present costs in current dollars. Since this entails the forecasting of inflation in addition to the many other forecasts, this would, by necessity, introduce another element of uncertainty into the analysis. To avoid this, it is suggested that all cost data be calculated in constant dollars for a base year, usually the one in which the analysis is performed. As discussed above, this will require that past costs be updated for inflation so that they are expressed in constant dollars for the base year. This adjustment is based on historical data provided by price indices and does not involve the element of uncertainty associated with estimating future inflation. The only adjustment to future expenditures will involve present value analysis discussed earlier.

Step 4. Estimate the Noise Reduction Resulting from Each Countermeasure

Making estimates of the noise reduction of countermeasures is, in some cases, simpler, and in others, more complicated, than estimating countermeasure costs. For a fixed noise reduction of a steady state stationary source such as an industrial plant, only one number must be estimated – the actual decibel (L_{eq}) reduction – whereas the costs may include equipment costs, maintenance costs, regulation administration costs, etc. On the other hand, to estimate the average noise reduction in the community due to the regulation of motorcycles, a number of complicated assumptions and manipulations are involved. To assist in this task, a short computer program is provided in Appendix B to this manual which computes the decibel reduction (L_{eq} fleet noise level) which results from noise regulations on many individual sources of a given type, such as air conditioners or automobiles. The program, originally intended to compute vehicle statistics, is called VESTA. Reference is made to VESTA in many of the discussions below on noise reduction estimates.

In each case, the noise reduction estimated for each countermeasure is the number of decibels by which the source L_{eq} is reduced in the community. It is assumed, for most of the countermeasures, that a given noise reduction is applied equally to all cells in the community where the source is found. For instance, if one countermeasure stipulates that a new muffler is required on all cars which makes each car 5 dB quieter, then in a cell where the original daytime L_{eq} from cars is 55 dB, the new daytime car L_{eq} is 50 dB, and in a cell where the original level is 75 dB, the new level is 70 dB. This of course does not apply to barriers. The noise reduction from a barrier is defined only for those cells which are in close proximity to it.

Step 5. Establish Cost Functions for Each Countermeasure by Pairing the Costs with Associated Noise Reductions

As mentioned above, for discrete step cost functions, obtain only one cost/noise reduction pair of values. For continuous cost functions, obtain a number of such pairs. Then proceed to Chapter 4 and operate the cost-effectiveness program.

Individual discussions for each noise abatement alternative follow.

3.4.1 Noise Standard (Operational)

An operational noise standard establishes a limit on noise emissions of products or activities in the field. The limit may refer to levels measured at a reference distance from the source of noise, or it may refer to levels measured at the property line. It requires administration and enforcement on the part of the city government and usually involves some cost of compliance to owners or operators of the regulated product.

The arithmetic operations indicated below and in other sections should be performed one step at a time, beginning from the top to the bottom.

1. Costs

A. Annual costs to the City

	$M_{A/E}$	Annual man-months required for administration/enforcement
x	C_E	Monthly employee cost
x	D_1	Discount factor for year when annual costs to city begin
x	11	Discount factor to account for continuous annual future funding
=	ⓐ	Total annual costs to the city

B. Annual Costs to Others

	C_O	Additional annual cost (if any) of operating equipment, per piece
x	Q	Number of pieces of modified equipment
+	C_L	Annual cost to operator of additional labor and administration
x	D_2	Discount factor for year when annual costs to operator begin
x	11	Discount factor to account for continuous annual future funding
=	ⓑ	Total annual costs to others

C. One-Time Costs to Others

	C_A	Cost to operator of altering equipment, per piece
x	Q	Number of pieces of modified equipment
+	C_T	Cost (if any) to retrain operators of modified equipment
x	D_3	Discount factor for year when one-time costs to operator occur
=	ⓒ	Total one-time costs to others

Total cost of countermeasure = ⓐ + ⓑ + ⓒ

Fraction of costs incurred by city = ⓐ ÷ (ⓐ + ⓑ + ⓒ)

2. Noise Reduction

A. Single Source

If a single source is being regulated, such as a power plant or a community concert hall, take the following steps to find the noise reduction.

Step 1. Identify the Average Noise Levels Produced at Different Times of Day and the Portion of Time Associated with Each Level

If a source of noise is either "on" or "off," determine the portion of time spent in each mode and determine the average noise level (L_{eq}) associated with each mode. If there are intermediate modes of operation, such as "halfway on," find the levels and portions of time associated with these modes. The results of the acoustical survey may be useful in identifying this data.

Step 2. Estimate the New Noise Levels for Each Mode of Operation Due to the Regulation

For instance, if a noise regulation specifies a maximum of 70 dB at the property line near a rock quarry, drilling operations may be reduced from 73 to 68 dB, but truck noise may remain at 65 dB. The noise reduction is then 5 dB for the period of time when drilling takes place, but 0 dB for periods when trucks are operating.

Step 3. Find the Total Noise Reduction from the Following Expression:

$$\Delta = L\,(\text{original}) - L\,(\text{new})$$

$$= 10 \log_{10}\left(\sum_i t_i \cdot 10^{L_i^o/10}\right) - 10 \log_{10}\left(\sum_i t_i \cdot 10^{L_i^n/10}\right)$$

where:

t_i is the fraction of time spent in the i^{th} mode,

L_i^o is the original average noise level (L_{eq}) of the i^{th} mode,

L_i^n is the new average noise level (L_{eq}) of the i^{th} mode.

Complete these steps for two different noise regulation levels – one strict, and one less strict. The two noise reduction values obtained are the "maximum" and "minimum" noise reductions required by Noizop for each stationary source.

B. Multiple Sources

Find the noise reduction of multiple noise sources such as construction equipment, traffic vehicles, other vehicles, and domestic equipment, by applying the procedure described below.

Step 1. Obtain Mean and Standard Deviation Values of Present Noise Levels Produced by the Noise Source Population Under Typical Operating Conditions

If data are available for your community, obtain noise levels of the source in question in terms of the L_{eq} observed over a specified sampled time period at a reference distance. Combine these sampled levels into a histogram. For simplicity, it may be assumed that the shape of the histogram can be approximated by a Gaussian distribution curve. Fit such a curve as closely as possible to the data, noting the mean and standard deviation. If no community-specific data is at hand, use the default values shown in Table 3-11.

Table 3-11

Default Values in dB To Be Used in Estimating Present Noise Levels of Selected Sources[13]

Source	Existing Population, Typical Operating Conditions			
	Low Speed (Urban Street)		High Speed (Highway)	
	Mean	σ*	Mean	σ*
Trucks	85.0	3.7	85.5	3.5
Autos	65.0	3.7	75.0	3.5
Motorcycles	76.0	2.9	80.6	2.8

* σ = standard deviation

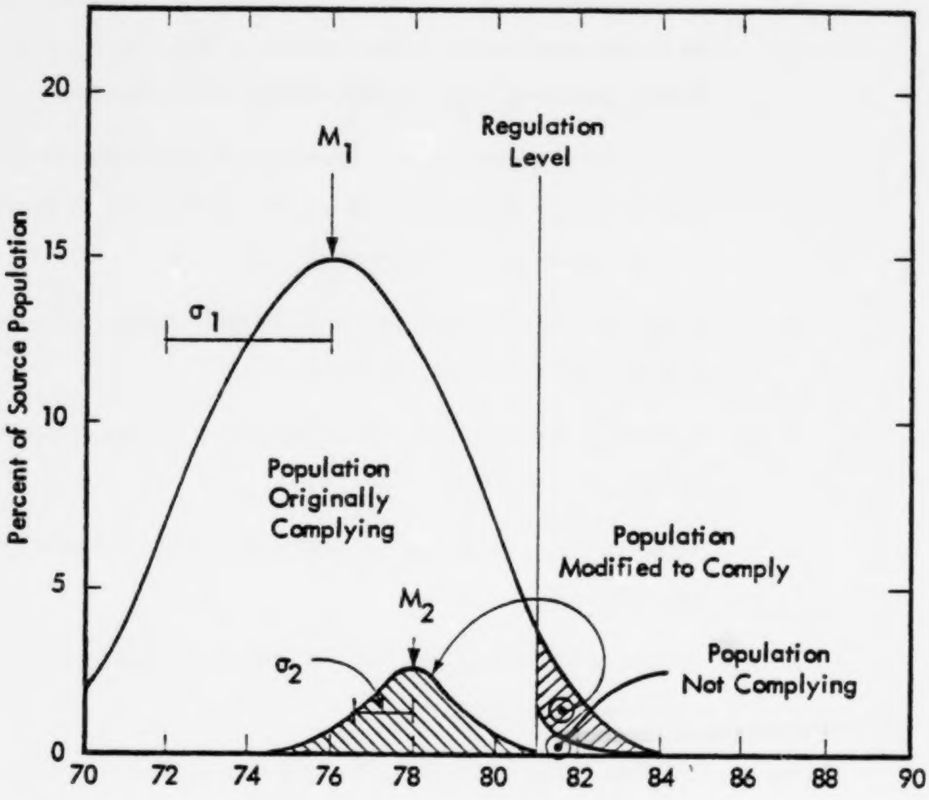
Step 2. Establish Regulation Level(s)

To properly establish a cost function for the noise standard alternative, at least two to three potential regulation levels must be quantified in terms of their costs to implement and their effectiveness in reducing source noise levels. Once a number of cost/effectiveness data points are defined and a curve is constructed, Noizop will eventually select a point on the curve which is optimal with respect to all alternatives being considered. This point may indicate a regulation level which lies between specified data points. In order to ensure that the selected level does not lie outside the range of the constructed cost/effectiveness curve, choose "potential" regulation levels at broad intervals. For instance, if a regulation level of 81 dB is being considered for the source whose noise level distribution is given in Figure 3-10, choose a regulation at 83 dB — where only very little change in source noise levels would be effected, and a regulation at 77 dB — where substantial changes in noise levels would be expected to occur.

Step 3. Obtain Mean and Standard Deviation Values of Noise Levels Produced by that Portion of the Source Population Which is Modified as a Result of the Abatement Measure

Figure 3-10 shows the manner in which the distribution of noise levels is changed due to the establishment of an operational noise standard. A major portion of the sources exceeding the standard are modified to comply. The modifications cause various degrees of noise reductions for each individual vehicle, but overall, the newly complying vehicles may be assumed again to be distributed in a Gaussian distribution. Estimate the mean and standard deviation of this new distribution for each "potential" regulation. Also, estimate the fraction of the source population originally exceeding the potential standard which is expected to be modified. This fraction depends on the level of enforcement which local agencies can provide, and on the regulation noise level itself. The greater the enforcement and the higher (less strict) the regulation level, the larger the fraction of sources which might be expected to comply.

With these items of information, estimate the noise reduction obtained with an operational noise standard by using the VESTA computer program. The program listing and a discussion of the arrangement of input data and interpretation of the output listing are provided in Appendix B.



Operational Noise Level at a Reference Distance, in dB (M_1 and σ_1 - Mean and Standard Deviation of Original Population M_2 and σ_2 - Mean and Standard Deviation of Modified Population)

Figure 3-10. Illustrative Example of Redistribution of a Source Population to Comply with a Regulation

3.4.2 Operational Controls

An operational control may consist of any one of a number of different actions. The following is a partial list (in approximate order of the noise source which is primarily affected, as listed in Table 3-2).

- Plant equipment operation specifications (for instance, not more than three drop hammers may operate at once, or a steam valve release shall only occur at less than a certain pressure).
- Idle operations control (for instance, air compressors shall not run idle for longer than 2 hours at a construction site, or buses shall not idle longer than 15 minutes at a bus stop).
- Flight controls (for instance, aircraft shall approach an airport with decelerating approach pattern.
- Vehicle excessive speed control (such as a change from 80 to 64 kmh (50 to 40 mph).
- Acceleration control (such as a prohibition against unnecessary hot-rodding).
- Accessory equipment controls (for instance, sirens shall be operated only when necessary).

For each of these types of actions, the cost components are somewhat similar; noise reduction estimates, however, are different and require separate discussions.

1. Costs

A. Annual Costs to the City

$M_{A/E}$ Annual man-months required for administration and enforcement
× C_E Monthly employee cost
× D_1 Discount factor for year when annual costs to city begin
× 11 Discount factor to account for continuous annual future funding
= ⓐ Total annual costs to the city

B. Annual Costs to Others

	C_O	Additional cost of operating equipment, per piece
x	Q	Number of pieces of equipment for which new operating procedures are required
+	C_L	Cost to operator of additional labor and administration
x	D_2	Discount factor for year when annual costs to operator begin
x	11	Discount factor to account for continuous future funding
=	ⓑ	Total annual costs to others

C. One-Time Costs to Others

	C_S	Cost due to delays in scheduling (example delays costs are shown in Table 3-12).*
x	W	Wholesale price index for industrial commodities*
+	C_T	Cost to retrain operators
x	D_3	Discount factor for year when one-time costs to others occur
=	ⓒ	Total one-time costs to others

Total Cost of Countermeasure = ⓐ + ⓑ + ⓒ

Fraction of Costs Incurred by City = ⓐ ÷ (ⓐ + ⓑ + ⓒ)

---

*Required, if the control pertains to construction noise, to update costs to current values (see Reference 12).

Table 3-12

Cost of Delays in Construction Schedule (C_S)[14]

Type of Development	Estimated Dollar Cost (1977 Dollars) of Delay in Schedule		
	Low	Medium	High
$30,000 Home			
Cost per day	$ 14	$ 18	$ 22
Cost per month	443	570	686
Cost per year	5,322	6,838	8,236
$50,000 Home			
Cost per day	25	31	38
Cost per month	739	949	1,143
Cost per year	8,871	11,396	13,727
$300,000 Multi-family Development			
Cost per day	145	185	224
Cost per month	4,694	5,666	6,831
Cost per year	52,836	67,988	81,974
$300,000 Commercial Development			
Cost per day	154	198	241
Cost per month	4,694	6,022	7,317
Cost per year	56,333	72,261	87,801
$300,000 Industrial Development			
Cost per day	146	188	225
Cost per month	4,435	5,730	6,864
Cost per year	53,225	68,765	82,362

2. Noise Reduction

Operational controls applied to a single noise source, such as an industrial plant, yield noise reductions which can be calculated in the same way as the method described under Section 3.4.1(2A). Other types of operational controls listed at the beginning of this section are described below.

A. Idle Operations Control

The noise level of a source typically depends on its operational mode. For motor vehicles, the principal modes are acceleration, deceleration, cruise, and idle, whereas for mobile construction equipment, high and low idle are often the two most appropriate acoustically differentiating modes. If operation in one mode is to be reduced, such as with an idle operations control, estimate the noise reduction obtained by following these steps:

Step 1. Estimate the Fraction of Time Presently Spent by the Source in Each Mode

Step 2. Identify the Average Noise Level Associated with Each Mode (All Levels Must Be Measured at the Same Distance from the Source)

Step 3. Estimate the Fraction of Time which Would Be Spent by the Source in Each Mode if an Idle Operations Control Were Introduced

Step 4. Estimate the Resulting Noise Reduction from the Following Equation:

$$\Delta L_{eq} = 10 \log\left(\sum_{i=1}^{m} t_i \cdot 10^{L_i/10}\right) - 10 \log\left(\sum_{i=1}^{m} t_i' \cdot 10^{L_i/10}\right)$$

where:

t_i is the fraction of time presently spent by the source in the i^{th} mode

t_i' is the fraction of time which would be spent in each mode if an operations control were introduced

m is the number of modes,

and L_i is the energy average noise level of the i^{th} mode.

Note that $\sum_{i=1}^{m} t_i = 1.0$ and $\sum_{i=1}^{m} t_i' = 1.0$; that is, the equation above applies when the reduction of time spent in one mode causes a corresponding increase in time spent in another mode. If the operations control reduces the overall time of operation, the equation above may still be used if the new mode operation fraction values t_i' are defined as fractions of the old operating duration.

As an example, let us assume an idling restriction is applied to buses — no bus may operate in idle for longer than 15 minutes in the same spot. This restriction will have two consequences: some bus drivers may turn off the engine after 15 minutes, while others may just move to a new location if they feel that the engine must remain at idle for a longer period of time. If the engine is turned off, the fraction of the time spent idling is reduced, say, from .1 to .05, but the other mode (nonidling) fractional times remain unchanged. As a result, $\sum_{i=1}^{m} t_i = 1.0$, but $\sum_{i=1}^{m} t_i' = 0.95$. (The engine was turned off for that .05 of the time that it was previously idling.) If, on the other hand, the bus continues to idle but now in a different location, the total amount of time spent idling may be unchanged but the fraction of the time spent in other modes increases since the bus has to accelerate, cruise, and decelerate to move to a new idling location. In this case, both $\sum_{i=1}^{m} t_i = 1.0$ and $\sum_{i=1}^{m} t_i' = 1.0$ if the overall amount of time that the bus is operating is now increased. In most cases, increasing other modes at the expense of idling would be quite undesirable from the overall standpoint of noise control.

B. Flight Controls

While control over the flight patterns and operations of aircraft comes under the jurisdiction of the Federal Aviation Administration, changes suggested by local authorities can be considered if safety is not adversely affected. Some operational changes which may help reduce noise impacts are:

- Power cutback after takeoff
- Flap management at approach
- Decelerating (low power) approach

These options have complex consequences, and their associated noise reductions are difficult to estimate, even with complex computer programs. If an alternative of this sort is desired, however, the FAA Integrated Noise Model computer program[15] (or latest version thereof) may be used to predict the noise reduction obtained at the appropriate locations in the community (these locations are the cells lying within or near the airport noise zones; see Section 3.3).

C. Speed Controls

A reduction of the speed limit in some areas of the city will reduce noise levels caused by motor vehicles only if the original noise levels are high enough that the tire noise component contributes substantially. In this case, a reduction from 87 km/h (55 mph) to 72 km/h (45 mph) will be more effective than from 72 km/h (45 mph) to 56 km/h (35 mph). In the same situation, a reduction from 56 km/h (35 mph) to 40 km/h (25 mph) may not have any noise reduction benefit at all. However, to a first approximation, this anomaly can be ignored and the following equations can be used to estimate the reduction of energy average levels of motor vehicles which would occur if a new speed limit were introduced:[6]

Autos: $\Delta L_A = 30 \log[V_1/V_2]$, dB

Trucks: $\Delta L_T = 26 \log[V_1/V_2]$, dB

where V_1 is the present average speed of vehicles (in km/h or mph),
and V_2 is the estimated future reduced speed of vehicles (in km/h or mph)

If a "Highway" is the problem noise source for which a speed control is desired, the highway noise reduction may be roughly estimated by combining the reductions established in the above equations with the fraction of vehicles they represent. For instance, establishing a new speed limit for a highway composed of 90 percent auto traffic (.9) and 10 percent trucks (.1) would reduce noise by an estimated:

$$\Delta L_{HWY} = 10 \log \left(.90 \cdot 10^{L_A/10} + .10 \cdot 10^{L_T/10} \right) - 10 \log \left(.90 \cdot 10^{(L_A - \Delta L_A)/10} + .10 \cdot 10^{(L_T - \Delta L_T)/10} \right), \text{dB}$$

where L_A is the original L_{eq} contributed by autos to the highway

L_T is the original L_{eq} contributed by trucks to the highway

ΔL_A is computed above

and ΔL_T is computed above

A more precise method of determining the change in auto, truck and highway noise levels is obtainable by consulting the EPA Highway Noise Impact Review Manual.[16]

D. Acceleration Control

The goal of this final operational control is to reduce unnecessary accelerations and engine run ups by motor vehicles. If a noise standard is written which makes it illegal to accelerate a motor vehicle in an unnecessarily rapid, loud, or periodic manner, the number of such accelerations would decrease. In terms of our mode model, the time spent accelerating is reduced by some amount and is added to the time spent cruising or accelerating at a regular rate.

To find the noise reduction associated with an acceleration or excessive run-up control, complete the following steps:

Step 1. Estimate the Fraction of Time Presently Spent by the Noise Source in Each Mode of Operation

This is the same as Step 1 under "Idle Operations Control" above. Estimate the average fraction of the time spent by a given type of noise source or vehicle accelerating excessively using the following equation:

$$P_{ea} = \frac{n}{N} \quad (P_a \cdot P_e)$$

where

P_{ea} is the population average fraction of the time a vehicle spends accelerating excessively,

n is the number of vehicles which accelerate excessively,

N is the total number of vehicles,

P_a is the average fraction of the time spent accelerating under any conditions,

and P_e is the fraction of accelerations which are excessive for those vehicles which accelerate excessively.

Step 2. Identify Typical Maximum Passby Noise Levels for All Modes of Operation

In this step, include excessive accelerations. This is the same as Step 2 under "Idle Operations Control" above.

Step 3. Estimate to What Degree an Acceleration Control Will Reduce the Number of Excessive Run Ups and Accelerations

This is accomplished by using the following equation:

$$P'_{ea} = \frac{n'}{N} \quad (P_a \cdot P'_e)$$

where

P'_{ea} is the new population averaged fraction of the time each vehicle spends in excessive acceleration,

n' is the new reduced number of vehicles which accelerate excessively,

and P'_e is the new reduced fraction of accelerations which are excessive for the n' vehicles.

The concept here is that an ordinance against excessive run ups and accelerations will have two consequences: (1) the number of vehicles (n) which accelerate excessively at all will be reduced (to n'); and (2) the fraction of accelerations which are excessive (P_e) for these n' vehicles will also be reduced (to P'_e).

Step 4. Estimate the Resulting Noise Reduction for this Alternative

Compute the estimated noise reduction by using the equation provided in Step 4 under "Idle Operations Control."

3.4.3 Area Restrictions

An area restriction prohibits the operation of certain noise sources in noise-sensitive areas. This measure requires city administrative and enforcement activity, and may add costs to operations involving the restricted products. Motor vehicles are the primary targets of area restrictions, espectially large trucks.

1. Costs

A. Annual Costs to the City

$M_{A/E}$ Annual man-months required for administration/enforcement

× C_E Monthly employee cost

× D_1 Discount factor for year when annual costs to city begin

× 11 Discount factor to account for continuous annual future funding

= ⓐ Total annual costs to the city

B. Annual Costs to Others

C_O Additional cost of operating equipment, per piece

× Q Number of modified pieces of equipment (here, "modified" means that the restricted area is now avoided)

× D_2 Discount factor for year when annual costs to others begin

× 11 Discount factor to account for continuous annual future funding

= ⓑ Total annual costs to others.

Total Cost of Countermeasure = ⓐ + ⓑ

Fraction of Costs Incurred by City = ⓐ ÷ (ⓐ + ⓑ)

2. Noise Reduction

A restriction which limits the area in the community where a noise source may operate may result in complete elimination of the noise produced by that source in that area, or it may only remove a fraction of the source population and result in a minor noise reduction. If Table 3-2 on page 3-4 indicated that an area restriction should be considered for a particular "problem noise source," define at least two scenarios which would cover the range of possible strictness of the area restriction so that Noizop can choose the most appropriate fraction of sources to remove. This fraction is paired with costs to define the cost function. For example, if trucks are found to be a problem in "Residential Area A," use the procedures below to estimate what fraction of trucks producing noise at a sample cell in Area A are affected by two hypothetical cases such as the following: (1) all through trucks prohibited from using the major arterial nearest the sample cell; and (2) all through trucks prohibited from using any arterials in Area A. These two cases will define two points on the cost curve. If Noizop decides that the most cost-effective expenditure for this abatement measure lies between the two points defined, this indicates that a restriction of intermediate strictness is recommended, such as (3) "through trucks only prohibited from using three major arterials in Residential Area A."

For an area restriction applied to motor vehicles, estimate the fraction of the source population affected by a particular scenario from the following equation:

$$f = \frac{\sum_i (\Delta d_i \cdot V_i)}{\sum_i (d_i \cdot V_i)}$$

where

f = the fraction of the source population affected,

Δd_i = the road length restricted in the i^{th} category,

V_i = the Average Daily Traffic (ADT) volume in the i^{th} road category, and

d_i = the total road length in the i^{th} category in the area surrounding the sample cell.

Road categories may be divided into four groups: (1) local streets; (2) feeders and collectors; (3) arterials; and (4) limited access highways. To use the above equation, estimate (1) the average volume of traffic, V_i, on each type of road; (2) the length of each road type, d_i, in the surrounding area (within a few kilometers of the sample cell); and (3) the length of road which will have restrictions placed on it, Δd_i.

For an area restriction applied to a population of stationary sources such as air conditioners, which may be assumed to be evenly distributed in the community, estimate the fraction of the source population affected by a particular area restriction scenario from the following equation:

$$f = \frac{\Delta A}{A}$$

where ΔA = the area (in square kilometers) affected by the restriction, and

A = the total area (in square kilometers) surrounding the sample cell (generally within a few kilometers of the cell).

3.4.4 Time Restrictions

Time restrictions may be applied to a wide variety of noise sources. They generally are designed to reduce the noise produced during the nighttime hours, the most noise-sensitive time of day. The city incurs administrative and enforcement costs and potential loss of tax revenue due to a reduced employment base with this alternative, while operators of restricted products may face time delays, reduced sales, and additional administrative costs.

1. Costs

A. Annual Costs to the City

	$M_{A/E}$	Annual man-months required for administration/enforcement
x	C_E	Monthly employee cost
=	ⓐ	Recurring annual administration/enforcement costs

	E_R	Reduction of employees, in man-years
÷	E	Number of employees in city
x	R	Annual municipal income and sales tax revenues
=	ⓑ	Recurring annual loss in tax revenue due to reduced employment base

	ⓐ	Recurring annual administration/enforcement costs
+	ⓑ	Recurring annual loss in tax revenue due to reduced employment base
x	D_1	Discount factor for year when annual costs to city begin
x	11	Discount factor to account for continuous annual future funding
=	ⓒ	Total annual costs to the city

B. Annual Costs to Others

(1) Commercial or Industrial Noise Sources and Airports

	S_R	Sales during restricted hours, per year
-	S_S	Sales expected to shift to nonrestricted hours
=	ⓓ	Recurring annual costs due to sales losses

(2) Construction Noise Sources

C_S Cost due to delays in schedule (example delay costs are shown in Table 3-12)

x W Wholesale price index for industrial commodities[12]

= ⓔ Recurring annual increased construction costs

ⓓ or ⓔ Sales losses or construction costs

+ C_L Cost to operator of additional labor and administration

x D_2 Discount factor for year when annual costs to others begin

x 11 Discount factor account for continuous annual future funding

= ⓕ Total annual costs to others

Total Cost of Countermeasure = ⓒ + ⓕ

Fraction of Costs Incurred by City = ⓒ ÷ (ⓒ + ⓕ)

2. Noise Reduction

Gather two items of information to define the effects of this measure.

1. The fraction of nighttime operations which are curtailed

   As an example, let us assume that a power plant is required to eliminate operations which produce excessive noise between 2 a.m. and 5 a.m. Then if operations were originally distributed evenly through the nighttime period (10 p.m. to 7 a.m.), the fraction which is curtailed is 3 ÷ 9 hours or .333.

2. The corresponding fractional increase, if any, in daytime operations

   If a nighttime operational restriction causes an increase in daytime operations, estimate the fractional increase which occurs.

These two items of information are input directly into Noizop which then calculates the noise reduction which results.

3.4.5 Permits

Permits may restrict the (1) duration, (2) frequency, (3) location, or (4) time of operation of a noise source. The first two types of permits are treated here. Area restrictions were discussed in Section 3.4.3, and time restrictions were discussed in Section 3.4.4. Extensive administrative costs are incurred by the city in issuing permits. Costs due to delays in scheduling and increased administrative costs and, in some cases, reduced sales, are borne by permittees.

1. Costs

A. Annual Costs to the City

	$M_{A/E}$	Annual man-months required for administration/enforcement
×	C_E	Cost of employee
×	D_1	Discount factor for year when annual costs to city begin
×	11	Discount factor to account for continuous annual future funding
=	ⓐ	Total annual costs to the city

B. Annual Costs to Others

	C_L	Cost to operator of additional labor and administration
+	C_S	Cost due to delays in schedule
+	S_E	Sales lost due to elimination of operation (applies to rock concerts not held, construction projects not permitted, recreational events not staged, etc.)
×	D_2	Discount factor for year when annual costs to operator begins
×	11	Discount factor to account for continuous annual future funds
=	ⓑ	Total annual costs to others

Total Cost of Countermeasure = ⓐ + ⓑ

Fraction of Costs Incurred by City = ⓐ ÷ (ⓐ + ⓑ)

2. Noise Reduction

If a permit limits the amount of source activity which may take place, such as a limit on the total number of construction days at any one site, or a limit on the number of consecutive hours a race track may operate, estimate the fraction of operations that are curtailed. If a permit limits the number of operations per unit time a source may be operated, such as a limit of blasting operations to one every 15 minutes, again estimate the fraction of operations which would be eliminated as a result of the restriction. Pair this fraction with its associated costs and provide this input data to Noizop.

3.4.6 Barriers

The construction of barriers along highways and railroad lines, and around commercial or industrial sources, can be very effective in reducing the noise impact on people living near these sources, but the remainder of the community will not be affected. Barriers are usually funded from local government sources; however, state or federal funding is often involved, so the costs attributed to the local government may not actually be paid directly from the city budget. If local data are not available, use the barrier costs supplied in Table 3-13.

Table 3-13

Cost of Barriers (from Reference 6)

Barrier Height in Meters (feet)		Application	Cost per Linear Meter (feet) 1977 Dollars	
3.0	(10)	Highway	$186	($ 57)
4.6	(15)	Highway/ Railroad	$281	($ 85)
6.1	(20)	Railroad	$425	($130)

1. Costs

A. Annual Costs to the City

	$M_{A/E}$	Annual man-months required for administration/enforcement
+	M_M	Annual man-months required for maintenance
x	C_E	Monthly employee cost
x	D_1	Discount factor year when annual costs to city begin
x	11	Discount factor to account for continuous annual future funding
=	ⓐ	Total annual costs to the city

B. One-Time Costs to the City

	C_B	Cost of barrier per linear meter (depends on barrier height)
x	L	Length of barrier in meters
x	W	Wholesale price index for industrial commodities
x	D_2	Discount factor for year when one-time costs to city occur
=	ⓑ	Total one-time costs to the city

Total Cost of Countermeasure = ⓐ + ⓑ

Fraction of Costs Incurred by City = 1.0

2. Noise Reduction

As an alternative to source noise regulations, area restrictions, and time restrictions, acoustic barriers can be constructed between the noise source and the receiver. The most important determinant of the effectiveness of noise barriers is the effective height of the barrier relative to the line of sight between the source and receiver. In practice, it has been shown that barriers generally produce noise reductions on the order of 10 dB, with a practical maximum attenuation of the order of 15 dB rarely actually occurring. The most effective permanent barrier design, from a cost and performance standpoint, appears to be a combination of a concrete or brick wall built on top of an earthen berm.

The noise optimization model requires two types of barrier noise reduction input data:

1. Barrier effectiveness ratios;
2. Noise reduction at the center of the affected cell(s).

These parameters may be specified for up to two alternate barrier heights. Barrier effectiveness ratios describe the effectiveness of barriers in attenuating noise from different sources relative to an established "norm." Each ratio is the noise reduction (in dB) of a source divided by the noise reduction of the "norm." Because they are the most prevalent noise source in the community, automobiles have been chosen as the "norm" source, and effectiveness ratios for other sources have been developed based on the effectiveness of barriers on automobiles. Such ratios are shown in Table 3-14 (a) for selected noise sources. Use this table to assign barrier effectiveness ratios to all problem sources defined in the community. Prepare ratios for two possible barrier heights: a low barrier (2 to 4 meters high), and a high barrier (4 to 6 meters high). Noizop will choose which barrier to build, if any, at each location, based on the different costs involved.

For each cell where a barrier is planned, the reduction of a noise level from a source is estimated in the computer model by multiplying the barrier effectiveness ratio of the source by the noise reduction estimated for automobiles. Two automobile noise reductions must be estimated for each barrier location: one for a high barrier, and one for a low barrier. Use Table 3-14 (b) to estimate the noise reduction in a cell affected by a barrier. If a barrier is planned with a height lying between the values listed, interpolate to find the appropriate automobile noise reduction.

If a barrier is planned along a major roadway, two cells will be affected by the barrier, as shown in Figure 3-2: one in Major Roadway Zone A, and one in Major Roadway Zone B. These are called the "primary cell" and the "secondary cell", respectively, in the cost-effectiveness model. Assign the same automobile noise reduction values to both the primary and secondary cells affected by a barrier along a major roadway.

Table 3-14

(a) Barrier Effectiveness Ratios for Low and High Barriers, by Noise Source[a]

Barrier Height in Meters (feet)	Autos and Motorcycles	Trucks and Buses		Rail[b]		Aircraft[c]
		Low Speed	High Speed	Locomotive	Cars	
2-4 (6.1-12.2)	1.0	0.7	0.9	0.3	0.8	0.0
4-6 (12.2-18.3)	1.0	0.9	1.0	0.4	1.0	0.0

[a] For nonvehicular noise sources (i.e., power plants, factories), estimate the ratio based on relative source height to the standard source - automobiles. Values based on noise reductions given in Reference 6.

[b] If the source noise levels are not separated for locomotives and cars, use an average of the two ratios.

[c] Zero effectiveness for aircraft in flight. For some areas along the sideline of airport runways or near aircraft engine test areas, where the dominant noise source is located on the ground, barriers can be effective - effectiveness ratios of 0.3 and 0.6 are estimated for 2-4 and 4-6 meter barrier heights respectively.

(b) Average Reduction of Automobile Noise by Low and High Barriers[6]

Barrier Height in Meters (feet)	Auto Noise Reduction in Cell Near Barrier (in dB)
2 (6.1)	10
3 (9.1)	13
4 (12.2)	14
5 or more (15.2 or more)	15

3.4.7 Building Insulation

In cases where exterior noise propagating into homes is intolerable to the citizens, the local government may elect to initiate a building insulation program. While insulating homes reduces impacts from all noise sources, it is usually applied only to homes underneath flight paths near airports. In many cases, a side effect of of sound insulation is a decrease in home heating costs during the winter, and air conditioning costs during the summer. Insulation costs and associated noise reductions may be estimated for three alternate levels of treatment: minimum, medium, and maximum. Noizop will decide which level of treatment, if any, to apply in each cell in the community based on these estimates.

1. Costs

A. Annual Costs to the City

	$M_{A/E}$	Annual man-months required for administration and enforcement
x	C_E	Cost of employee per month
x	D_1	Discount factor for year when annual costs to city begin
x	11	Discount factor to account for continuous annual future funding
=	ⓐ	Total annual costs to the city

B. One-Time Costs to the City

	C_1	Cost to insulate per square meter (depends on noise reduction desired for each building)
x	A	Floor area of buildings in each noise reduction category, square meters
x	D_2	Discount factor for year when one-time costs to city occur
=	ⓑ	Total one-time costs to the city

C. Annual Costs to Others

F Fuel savings per square meter (see Table 3-15 for typical values)
× D_3 Discount factor for year when costs to others begin
× 11 Discount factor to account for continuous annual future funding
= ⓒ Total annual costs to others

Total Cost of Countermeasure = ⓐ + ⓑ - ⓒ

Fraction of Cost Incurred by City = (ⓐ + ⓑ) ÷ (ⓐ + ⓑ - ⓒ)

This fraction will be larger than 1.0 in magnitude. For input to the optimization model, Noizop, use 1.0.

Soundproofing cost data must be input to Noizop as costs per square unit floor area for each of the three levels of soundproofing. Therefore, after computing the total composite costs above separately for each level, divide these values by the total floor area of all buildings in the community to be insulated to obtain unit floor area costs. The floor area of buildings to be insulated is input to Noizop with the cell data as described in Chapter 4 and in the Noizop User's Guide.

2. Noise Reduction

The cost of incremental improvement in building noise reduction achieved with noise insulation increases rapidly with the increase in noise reduction. Table 3-16 illustrates this relationship. If insulation cost figures are not available for your community, use the values supplied in this table, then compute the total costs of each noise reduction category as described above. Use these results to define three building insulation costs and associated reductions: a minimum treatment, a medium treatment, and a maximum treatment.

Table 3-15

Fuel Savings

Level of Insulation	Average Increase in Noise Reduction, dB	Typical Annual Fuel Savings (F) Per Square Meter (Square Foot) 1977 Dollars*					
		North		Midwest		South	
Minimum	5	$.083	(.0077)	$.044	(.0041)	$.020	(.0018)
Medium	10	.170	(.016)	.093	(.0087)	.044	(.0041)
Maximum	15	.258	(.024)	.142	(.013)	.069	(.0064)

*Based on methods of estimating fuel savings described in Reference 17, using the following assumptions:

(1) Annual number of days when outdoor temperature falls below 18°C (65°F) times the number of degrees below 18°C (65°F) =

North:	3900°C degree-days	(7000°F degree-days)
Midwest:	2200°C degree-days	(4000°F degree-days)
South:	1100°C degree-days	(2000°F degree-days)

(2) Average house size = 186 sq m (2000 sq ft), volume = 453 cu m (16,000 cu ft)

(3) Added ventilation requirements are considered, but they are small (less than $.002/cu meter)

(4) Cost of energy is $4/million BTU

(5) Linear relationship between degree of noise reduction and amount of reduction in heat losses by infiltration of outside cold air.

Table 3-16

Incremental Noise Reduction Achieved with Selected Levels of Insulation Applied to Existing Homes[18-21]

Level of Insulation	Insulation Cost (C_I) Per Square Meter (Square Foot) 1977 Dollars*		Average Increase in Noise Reduction, dB
Minimum	$ 32	($ 2.95)	5
Medium	$ 91	($ 8.40	10
Maximum	$165	($15.30	15

*Use Consumer Price Index for home ownership to update to current year.[12]

3.4.8 Compensation

Compensation usually refers to the money which is paid to residents living near airports under flight paths to compensate for the loss in land value caused by the excessive noise levels. Compensation does not reduce noise per se, but it tends to reduce peoples' complaints to noise, thereby reducing adverse community reaction to some extent. If the noise of airplanes flying over a resident's land damages the owner in the use of the land, the courts may decide that there is an "inverse condemnation" or a "taking" of property for which compensation must be paid either in the form of annual or one-time payments.

Residents who suffer noise pollution but whose airspace is not physically entered cannot usually claim inverse condemnation. Only governmental units with the power of eminent domain, such as the city or the airport commission, can be sued for the taking of property, and therefore these parties bear the entire compensation costs. Compensating people before suits are brought against the city may be a cost-effective action, although few examples of such action exist. Thus, compensation is treated here as a countermeasure which local governments may initiate. Costs are based on reductions in property value and rent caused by noise sources, although the local government could decide to provide compensation at a greater or lesser rate depending on considerations such as available funds and citizen demands.

1. Costs

A. Annual Costs to the City

	$M_{A/E}$	Annual man-months required for administration/enforcement
x	C_E	Monthly cost of employees
=	ⓐ	Recurring annual costs for administration/enforcement
	V_R	Annualized property value reduction due to aircraft flyovers, per household
x	H	Number of households affected
=	ⓑ	Recurring annual property value reduction costs

	ⓐ	Recurring annual costs for administration/enforcement
+	ⓑ	Recurring annual property value reduction costs
x	D_1	Discount factor for year when annual costs to city begin
x	11	Discount factor to account for continuous annual future funding
=	ⓒ	Total annual costs to city

B. One-Time Costs to the City

	V_R	Annualized property value reduction due to aircraft flyovers, per household
x	H	Number of households affected
x	Y	Average remaining physical life of impacted buildings, in years
x	D_2	Discount factor for year when one-time costs to city occur
=	ⓓ	Total one-time costs to city

Total Cost of Countermeasure = ⓒ + ⓓ

Fraction of Costs Incurred by City = 1.0

2. Noise Reduction

The relationship between property value reduction and noise levels has been studied by many researchers.[10, 22-24] On the basis of these investigations, the estimates shown in Table 3-17 were made. The estimates assume an initial average property value of $50,000 and an average rent of $350 per unit. The property reductions are "annualized;" that is, the total property value reduction of a home is the annualized reduction shown in the table times the number of years of physical life remaining for the building on the property. The figures are derived from studies of homes lying between the L_{dn} 55 to 80 dB airport contours for aircraft noise, and within 30m (100 ft) of the highway for highway noise.

Table 3-17

Annualized Property Value Reduction (V_R) in 1977 Dollars Due to Selected Increases in Noise Level [10, 22-24]

Source	Increase in Noise Level (dB)				
	5	10	15	20	25
Aircraft Noise	$220	$440	$660	$880	$1100
Highway Noise	$ 55	$110	$165	$220	$ 275

Use the relationship between dB increase and property value reduction in Table 3-17 to form the basis for the compensation cost function. The costs shown in the table, V_R, must be manipulated as described above to obtain the total annualized costs. The corresponding "noise reductions" are the increases in noise level associated with these costs in the table.

3.4.9 Population Relocation

If noise problems are severe enough in the community, as a last resort the affected residents can be relocated. Costs to the city government can be substantial but significant financial damage in the form of lost profits and goodwill also occurs if commercial establishments are moved. Relocation costs must be estimated for the entire population in each cell where relocation is a viable alternative.

1. Costs

A. Annual Costs to the City

	$M_{A/E}$	Annual man-months required for administration/enforcement
×	C_E	Monthly cost of employee
=	ⓐ	Recurring annual costs for administration/enforcement

	V_A	Average assessed value of property
x	T	Property tax rate, fraction of V_A
x	H	Number of households affected
=	ⓑ	Annual loss in property tax revenue

	ⓐ	Recurring annual costs for administration/enforcement
+	ⓑ	Annual loss in property tax revenue
x	D_1	Discount factor for year when annual costs to city begin
x	11	Discount factor to account for continuous annual future funding
=	ⓒ	Total annual costs to city

B. One-Time Costs to the City

	$1.-V_{L/P}$	One minus the ratio of land value to property value*
x	$4 \cdot V_A$	Four times the average assessed value of property**
+	C_R	Cost to relocate, per household
+	C_D	Cost of demolition, per household
x	H	Number of households affected
x	D_2	Discount factor for year when one-time costs to city occur
=	ⓓ	Total one-time costs to the city

---

*If the land purchased by the city is not usable for nonresidential purposes, such as parks, city offices, etc., remove this term.

**A multiplier of 4 is applied to the assessed property value to obtain the market value.

C. One-Time Costs to Others

	$3 \cdot S_P$	Three times net monthly sales for commercial properties acquired (12-month average)*
x	P	Number of commercial properties affected
x	D_3	Discount factor for year when one-time costs to others occur
=	ⓔ	Total one-time costs to others

Total Cost of Countermeasure = ⓒ + ⓓ + ⓔ

Fraction of Costs Incurred by City = (ⓒ + ⓓ) ÷ (ⓒ + ⓓ + ⓔ)

Note that the assessed value (V_A), tax rate (T), land-to-property ratio ($V_{L/P}$), relocating costs (C_R), and demolition costs (C_D) may be different for residences and commercial properties.

---

* An average of 3 months are required for commercial concerns to reestablish business at original levels.

2. Noise Reduction

No noise reduction values are needed.

3.4.10 Planning and Zoning

Planning and zoning is a noise control alternative which may take many years before the benefits are realized. The time lag depends on the municipal population growth rate, the portion of vacant land, and the number of older buildings in the community. Although the city may already have a planning/zoning department, some additional administrative and enforcement costs will be incurred if changes are made for noise control purposes. Changes in the tax base due to zoning changes will also affect the city revenues. If a change in the location of a highway is required, additional construction and relocation costs may occur. Property owners may suffer reduced property values as a result of the changes. It they must eventually move their business, relocation costs are also involved.

1. Costs

A. Annual Costs to the City

	V_A^o	Average assessed value of old property
x	T^o	Property tax rate for old property
=	ⓐ	Lost property tax revenue from old property
	V_A^n	Average assessed value of new property
x	T^n	Property tax rate for new property
=	ⓑ	Property tax revenue from new property
	U	Number of underdeveloped lots in areas to be zoned
+	B	Number of nonconforming buildings over 50 years old in areas to be zoned
=	ⓒ	Number of property units affected
	$M_{A/E}$	Annual man-months required for administration/enforcement
x	C_E	Monthly cost of employees, per month
=	ⓓ	Recurring annual administrative/enforcement costs

ⓐ Lost property tax revenue from old property

+ ⓑ Property tax revenue from new property

× ⓒ Number of property units affected

+ ⓓ Recurring annual administrative/enforcement costs

× D_1 Discount factor for year when annual costs to city begin

× 11 Discount factor to account for continuous annual future funding

= ⓔ Total annual costs to the city

B. One-Time Costs to the City

C_R^h Cost to relocate highways, if any

× D_2 Discount factor for year when one-time costs to city occur

= ⓕ Total one-time costs to the city

C. One-Time Costs to Others

$4 \cdot V_A^o$ Four times average assessed value of old property (to obtain market value)

- $4 \cdot V_A^n$ Four times average assessed value of new property (to obtain market value)

+ C_R^b Cost to relocate businesses, if any

× D_3 Discount factor for year when one-time costs to others occur

= ⓖ Total one-time costs to others

Total Cost of Countermeasure = ⓔ + ⓕ + ⓖ (if negative, use one dollar)

Fraction of Costs Incurred by City = (ⓔ + ⓕ) ÷ (ⓔ + ⓕ + ⓖ)

2. Noise Reduction

The impact of a community noise source may be reduced or eliminated through careful planning and zoning policies. If the noise levels from a major arterial are excessive, for instance, plans could be made to expand alternative routes which would effectively relocate the source through less sensitive areas of the community. Or zoning changes could be made which would limit the increase in population near high noise level areas, thus effectively "relocating" the injured population.

If the countermeasure involves relocating a noise source by the target year ("Planning"), estimate the new noise levels at each cell near its new location, or use the "-1" parameter in the Noizop path-receiver override array for relocation,[3] and, if old cells are still affected by the source, estimate the new reduced noise levels there. Include relocation costs in the total annual cost for this case. If the countermeasure involves "relocating" the population ("Zoning"), no relocation costs are incurred but only the costs due to administration, enforcement, and changes in property values. Calculate these costs for each cell which is affected by zoning changes. Noizop will then decide, on the basis of these costs, whether or not the zoning requirements are needed by deciding whether or not to relocate the population in the cell.

3.4.11 Building Codes

Building codes for residential construction may be established as a measure to reduce community-wide exposure to outdoor noise levels. As with planning and zoning changes, a time lag is involved, so the effects are not felt immediately. Expenses to the city include administrative and enforcement costs. Costs of conforming to the codes are borne by developers and/or buyers. Building owners may experience some fuel savings as a result of improved insulation requirements.

1. Costs

A. Annual Costs to the City

	$M_{A/E}$	Annual man-months required for administration/enforcement
x	C_E	Costs of employee, per month
x	D_1	Discount factor for year when annual costs to city begin
x	11	Discount factor to account for continuous annual future funding
=	ⓐ	Total annual costs to the city

B. Annual Costs to Others

	F	Annual fuel savings for buildings in each noise reduction category, per square meter
x	A	Floor area of buildings in each noise reduction category, in square meters
x	D_2	Discount factor for year when annual costs to others begin
x	11	Discount factor to account for continuous annual future funding
=	ⓑ	Total annual costs to others

C. One-Time Costs to Others

	C_C	Cost to conform to code, per square meter (depends on noise reduction for each building type) (based on current construction costs[12])
x	A	Floor area of buildings in each noise reduction category, in square meters
x	D_3	Discount factor for year when one-time costs to others occur
=	ⓒ	Total one-time costs to others

Total Cost of Countermeasure = ⓐ - ⓑ + ⓒ (if negative, use one dollar)

Fraction of Costs Incurred by City = ⓐ ÷ (ⓐ - ⓑ + ⓒ)

2. Noise Reduction

The noise reduction achieved with building codes, as with building insulation, depends on the degree of treatment. A building insulation program affects existing homes and, therefore, costs more per dB reduction than building codes, whose requirements can usually be incorporated at the design and initial construction stages without much additional trouble. If cost-to-conform (C_C) figures are not available for your community, use the values supplied in Table 3-18. They are based on the insulation costs of Table 3-16, using an estimated difference of 20 to 30 percent between the cost of insulating an existing home (i.e., weatherstripping and blown-in insulation) and the cost of insulating a home at the new construction stage.

Table 3-18

Estimated Increase in Noise Reduction Achieved
by Modifying New Construction Practices
with Selected Degrees of Building Codes,
by Cost to Conform[25]

Estimated Cost to Conform (C_C) per square meter (square foot), 1977 Dollars*		Average Increase in Noise Reduction, dB
$ 25	($ 2.40)	5
$ 68	($ 6.30)	10
$115	($10.70)	15

*Use Consumer Price Index for homeownership to update to current year.[12]

3.4.12 Tax Incentives

Tax incentives are provided by local governments to property owners who have noisy equipment located on their property in order to help pay for quieting that equipment. Costs of a tax incentive program are borne entirely by the local government in mose cases. The noise reduction which results depends on the noise level at which the incentive is applied, the cost to quiet the product, and other factors which are discussed below.

1. Costs

A. Annual Costs to the City

	$M_{A/E}$	Annual man-months required for administration/enforcement
x	C_E	Cost of employee, per month
+	R_C	Change in revenues due to the tax program (the method of estimating R_C is presented later)
x	D_1	Discount factor for year when annual costs to city begin
x	11	Discount factor to account for continuous annual future funding
=	ⓐ	Total annual costs to the city

Total Cost of Countermeasure = ⓐ

Fraction of Costs Incurred by City = 1.0

2. Noise Reduction

Figure 3-11 illustrates three types of tax incentives which a local government may wish to institute. They are: (1) fixed incentive; (2) incentive proportional to cost; and (3) incentive proportional to cost plus noise reduction.

A fixed incentive provides a tax break if a product is purchased and used which emits noise levels less than a specified criterion level. This is shown by the dashed line in Figure 3-11. For instance, a tax break of $300 may be allowed if an outdoor commercial

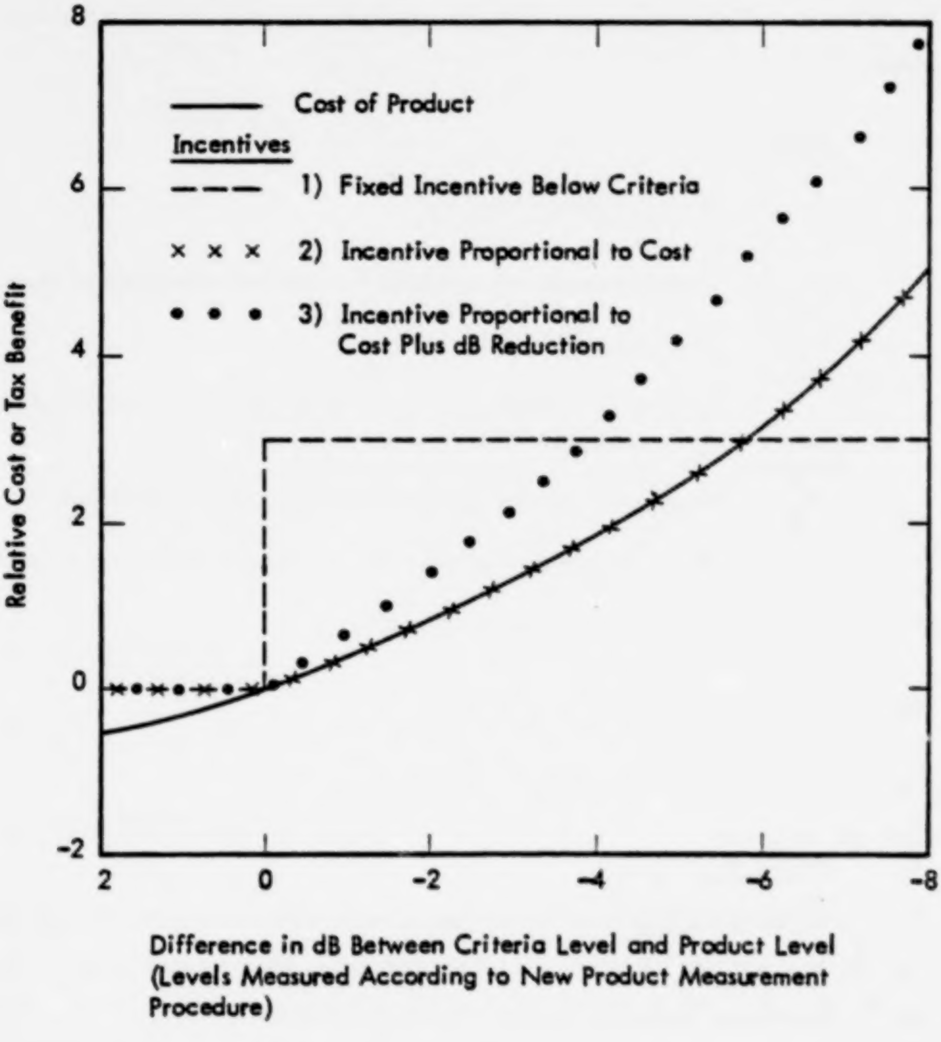


Figure 3-11. Three Possible Incentive Schemes to Bring Product Noise Levels Below a Criterion Level

ventilation system is installed which generates less than an L_{eq} of 60 dB at 15 meters. In this case, the owner of a system which produced 49 dB at 15 meters would receive the same benefit as the one which produced 59 dB.

The second type of incentive provides a tax break which is proportional to the additional cost required to purchase, install, and operate the quieter system. This is shown by the line of x's in Figure 3-11. For example, the owner of a product which costs $500 more than an average reference product but which is 8 dB quieter receives a tax credit of $500. As a result, any tendency to purchase noisier products just because they are cheaper is removed.

The third type of incentive provides a reduction of taxes beyond what additional costs are incurred to purchase the quieter product. This is shown by the dotted line in Figure 3-11. As an example, the purchase of a product which is 8 dB quieter than the reference product would be subsidized by $800, even though it costs only $500 more than the reference product. A scheme of this type provides an incentive to achieve lower and lower noise levels, however, the local government must be prepared to sacrifice a potentially significant portion of its tax revenues to pay for it.

Of the three types of incentives, the incentive which is proportional to incurred costs (type number 2) is probably the most appropriate for local government action. The first type of incentive, the fixed incentive, requires that information be gathered on what dollar figure is most equitable, and this "average" cost may be difficult to define. It would depend on technology available, year of purchase, number of items purchased, and other factors which may not all point to one reasonable single figure to use. Similarly, the third type of incentive, a tax incentive which is proportional to the degree of noise reduction achieved below some criterion level, also requires that information be gathered on how much money should be sacrificed by the local government in the form of lost revenues to pay for each decibel reduction. While this approach actually makes noise quieting a profitable venture to companies who take advantage of it, to the local government it could be too expensive to be worthwhile.

A scheme which provides, in effect, reimbursement for all marginal costs expended to purchase quieter products therefore appears to be the best approach. It is equitable, flexible, not overly costly, and effectively reduces noise emissions of the source population. Therefore, if this scheme is to be used, gather information on: (1) the average cost of products which emit noise levels which are approximately the same as the criterion level; and (2) the additional cost (if any) of products emitting noise levels which are lower than the criterion by specified amounts. Plot the differences in noise level (x-axis) versus the differences in cost (y-axis) found between the reference product(s) and the quieter products, using the legends shown in Figure 3-11. Establish the best-fit curve to these points. This curve determines the amount of money the local government will pay – or, equivalently, the amount of tax revenue which will be lost – to have new products quieted by given amounts.

New products manufactured after the incentive is established which exceed the criterion level may be expected to have their noise levels redistributed in more or less a uniform fashion below the criterion point since any incentive to purchase noisier products merely because they are cheaper is removed with the tax rebate. Plot this distribution of newly purchased new products as shown in Figure 3-12 (a) and identify the mean of the distribution. Additionally, estimate the percent of new products originally designed to exceed the criterion level which would now be expected to be redistributed below the cut-off.

A computer program (VESTA) is described in Appendix B and provides an estimate, based on the items of information computed above, of the average population-wide noise reduction of products affected by a countermeasure such as a tax incentive.

The change in revenues due to the tax incentive program (R_C) is approximately the difference in cost between a product at the noise criterion level and a product at the mean of the new distribution (M in Figure 3-12 (a)), times the total number of new, modified products.

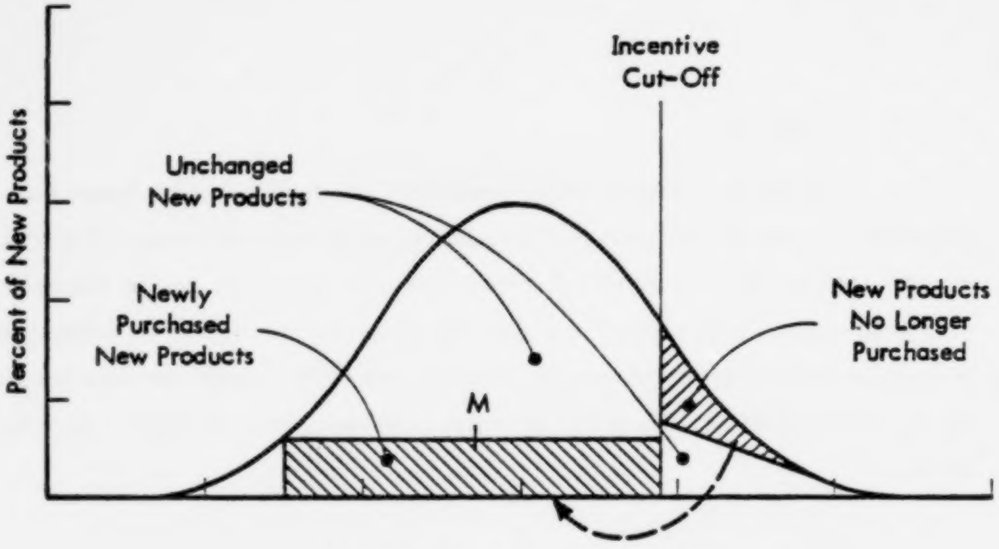


Figure 3-12.1(a). Redistribution of New Product Noise Levels Below a Cut-Off Due to an Incentive Proportional to Additional Costs Incurred (M = Mean of Redistributed New Product Noise Levels)

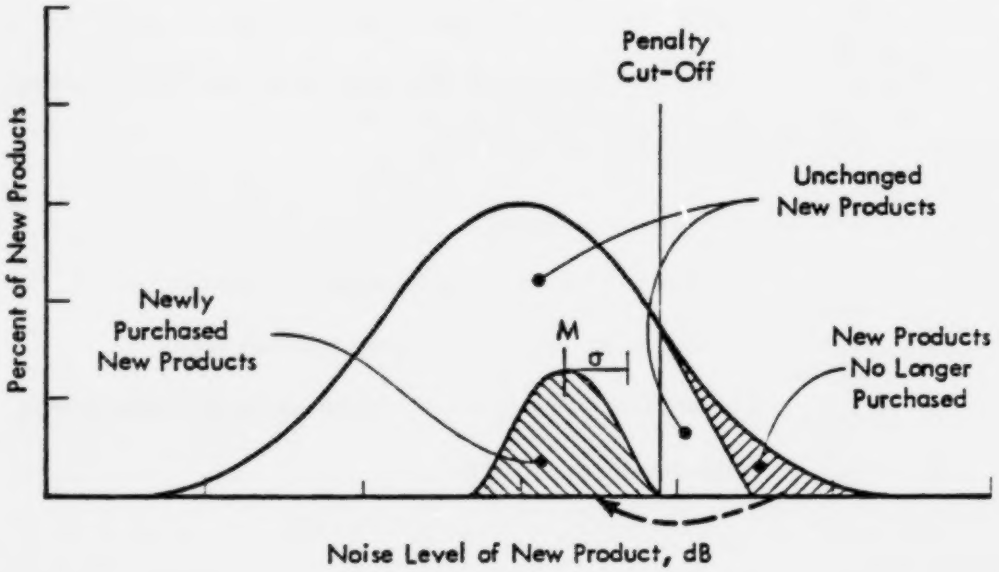


Figure 3-12.1(b). Redistribution of New Product Noise Levels Below a Cut-Off Due to a Penalty Proportional to Additional Costs Incurred Plus dB Above Cut-off (M = Mean of Redistributed New Product Noise Levels, σ = Standard Deviation)

3.4.13 Tax Penalty

A tax penalty scheme may be established which penalizes businesses for operating products or equipment which cause excessive community noise. The cost to the city involves administration and enforcement, although these may be balanced by revenues produced by the penalties. Costs to others include the cost to modify noisy products in order to avoid the penalty, plus the cost of the penalty for those products which are not modified. The noise reduction achieved depends on factors described below.

1. Costs

A. Annual Costs to the City

	$M_{A/E}$	Annual man-months required for administration/enforcement
x	C_E	Cost of employee, per month
-	R_C	Change (increase) in revenues due to tax program
x	D_1	Discount factor for year when annual costs to city begin
x	11	Discount factor to account for continuous annual future funding
=	ⓐ	Total annual costs to the city

B. Annual Costs to Others

	R_C	Penalties incurred for unmodified noisy equipment
x	D_2	Discount factor for year when costs to others begin
x	11	Discount factor to account for continuous annual future funding
=	ⓑ	Total annual costs to others

C. One-Time Costs to Others

	C_A	Cost to operator of altering equipment, per piece
x	Q	Number of modified pieces of equipment
x	D_3	Discount factor for year when one-time costs to others occur
=	ⓒ	Total one-time costs to others

Total Cost of Countermeasure = ⓐ + ⓑ + ⓒ

Fraction of Costs Incurred by City = ⓐ ÷ (ⓐ + ⓑ + ⓒ)

2. Noise Reduction

Figure 3-13 illustrates three types of tax penalties which a local government may wish to institute. They are: (1) fixed penalty; (2) penalty proportional to cost; and (3) penalty proportional to cost plus decibels above criteria.

A fixed penalty provides a tax on all products exceeding the cut-off level, independent of how much the cut-off level is exceeded. This is shown by the dashed line in Figure 3-13.

A penalty proportional to cost provides a tax which is equal to the additional cost required to purchase, install, and operate a product which meets the criterion level. This is shown by the line of x's in Figure 3-13.

The third type of penalty provides a tax on products in proportion to the degree to which the criterion level is exceeded. This is shown by the dotted line in Figure 3-13. This penalty scheme is the most appropriate scheme to use since it provides an incentive for the noisiest products to be quieted first, and, before they are quieted, the local government gains additional revenue in proportion to the disturbance they cause.

If this third penalty scheme is to be used, gather the same information defined earlier for "Tax Incentives" (Section 3.4.12); namely, (1) the average cost of products

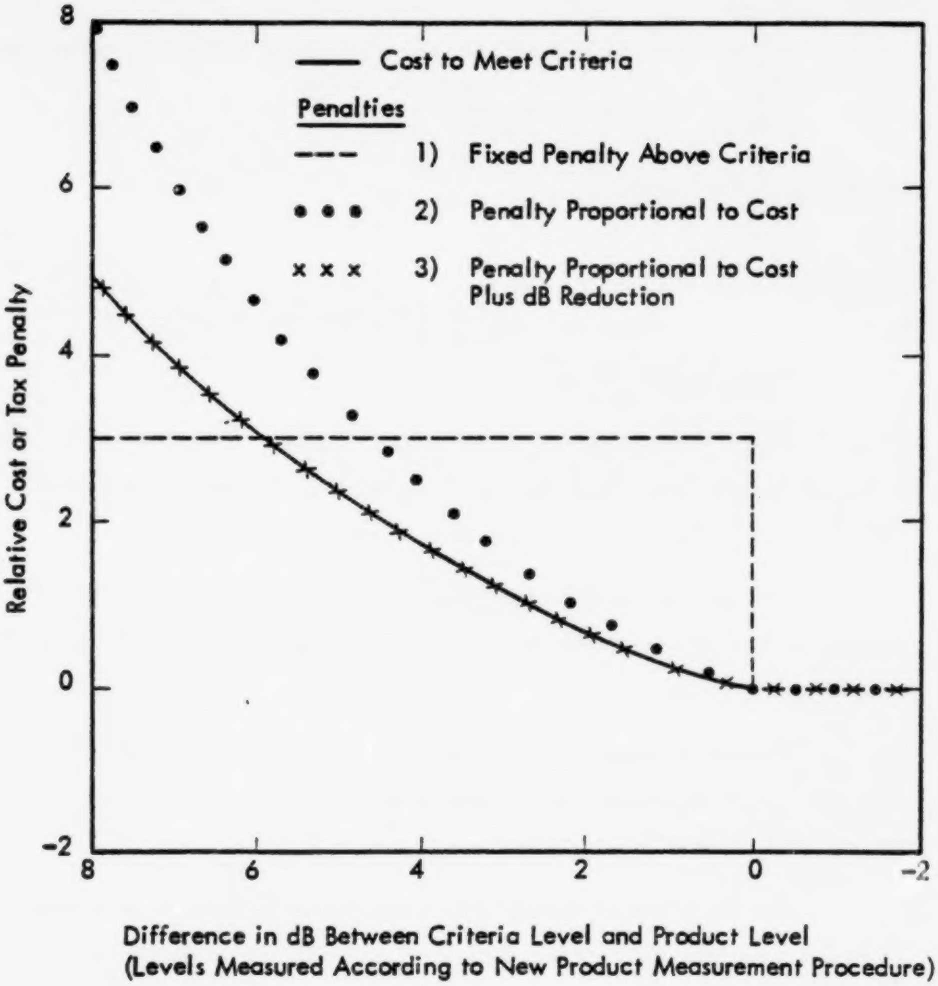


Figure 3-13. Three Possible Penalty Schemes to Bring Product Noise Levels Below a Criterion Level

which emit noise levels which are approximately the same as the level at which the penalty begins, and (2) the additional cost (if any) to the purchaser of products exceeding the criterion to purchase a product which is lower than the criterion. Plot the differences in noise level between the excessive and reference products (x-axis) versus their differences in cost (y-axis), using the legends shown in Figure 3-13. Establish a best-fit curve to these points. This curve establishes the amount of money that owners of new products must pay to the local government for the right to purchase noisy products.

After the penalty is established, new products which originally would have exceeded the penalty cut-off level may be expected to be modified as shown in Figure 3-12(b). Here, new products which would have incurred high penalties because of their excessive noise levels have been modified so that they no longer exceed the penalty cut-off. Estimate the mean and standard deviation of this distribution of "newly purchased" new products. Also, estimate the fraction of new products which are expected to be modified as a result of the penalty. Then use the VESTA computer program to find the noise reduction associated with the assumed regulation level. Find the noise reductions achieved with two to four different regulation levels, and pair these reductions with the associated total costs to define the cost function for this countermeasure.

3.4.14 Noise Standard (New Product)

A new product noise standard may only be established by a local government if state or federal laws do not preempt doing so. A local new product regulation requires additional municipal administration and enforcement. Manufacturers of regulated products incur additional labor, administrative, and product redesign and modification costs. Operators of new products redesigned to comply with a noise standard may incur additional operating costs and/or costs associated with retraining.

1. Costs

A. Annual Costs to the City

	$M_{A/E}$	Annual man-months required for administration/enforcement
x	C_E	Cost of employee, per month
x	D_1	Discount factor for year when annual costs to city begin
x	11	Discount factor to account for continuous annual future funding
=	ⓐ	Total annual costs to the city

B. Annual Costs to Others

	C_O	Additional cost (if any) of operating modified equipment, per piece
x	Q	Number of modified pieces of equipment
+	C_L	Cost to manufacturer of additional labor and administration
x	D_2	Discount factor for year when annual costs to others begin
x	11	Discount factor to account for continuous annual future funding
=	ⓑ	Total annual costs to others

C. One-Time Costs to Others

	C_A	Cost to manufacturer of altering equipment, per piece
x	Q	Number of modified pieces of equipment
+	C_T	Cost (if any) of retraining operators of modified equipment
x	D_3	Discount factor for year when one-time costs to others occur
=	ⓒ	Total one-time costs to others

Total Cost of Countermeasure = ⓐ + ⓑ + ⓒ

Fraction of Costs Incurred by City = ⓐ ÷ (ⓐ + ⓑ + ⓒ)

2. Noise Reduction

The redistribution of products originally exceeding a new product noise level has been graphically displayed in Figure 3-12. While there is no established procedure for estimating the mean and standard deviation of the distribution of modified products, it may be assumed that the mean is within a few dB of the new product regulation level. It also may be assumed that nearly 100 percent of the products will be in compliance with a new product regulation. With these assumptions, find the noise reduction associated with two to four different new product regulatory levels by using the VESTA program. By pairing the costs of these regulations with the corresponding noise reductions, establish the cost function for this countermeasure.

3.4.15 Labeling

A local government may require a noisy product to be labeled in some way so as to inform the consumer of the high noise levels which it produces. With this measure, the city will incur administrative and enforcement costs, and manufacturers will incur costs associated with complying with the labeling requirement. The noise levels of products will be reduced on the average only if consumers choose to buy more quiet products than they would if noise labels were not attached.

1. Costs

A. Annual Costs to the City

	$M_{A/E}$	Annual man-months required for administration/enforcement
x	C_E	Cost of employee, per month
x	D_1	Discount factor for year when annual costs to city begin
x	11	Discount factor to account for continuous annual future funding
=	ⓐ	Total annual costs to the city

B. Annual Costs to Others

	C_L	Cost to manufacturer of additional labor and administration
x	D_2	Discount factor for year when annual costs to others occur
x	11	Discount factor to account for continuous annual future funding
=	ⓑ	Total annual costs to others

C. One-Time Costs to Others

	C_A	Cost to manufacturer of altering equipment, per piece
x	Q	Number of modified pieces of equipment
x	D_3	Discount factor for year when one-time costs to others occur
=	ⓒ	Total one-time costs to others

Total Cost of Countermeasure = ⓐ + ⓑ + ⓒ

Fraction of Costs Incurred by City = ⓐ ÷ (ⓐ + ⓑ + ⓒ)

2. Noise Reduction

A labeling program may take many forms. Products may be labeled according to their noise level ("x dB"), their acceptance by the community ("Somewhat Annoying"), their relationship to other products of the same type ("Quieter than Average"), or their noise level with respect to a criterion ("Exceeds Recommended Limits"). The latter approach is considered as an example in the discussions below since it has the virtues of simplicity of description and ease of understanding and yet remains an objective rather than a subjective label.

Regardless of the form, as long as proper public education accompanies the regulation, it may be expected that a noise labeling program will cause more quiet products to be bought than before, and fewer noisy ones purchased. The degree of this change is difficult to estimate and is expected to vary according to the type of product, price, consumer preference, and locale. If a better method of estimating the mean and standard deviation of the new distribution is not available, use the same method as described above under Section 3.4.14, New Product Standard; in particular:

1. Divide the present distribution of new product noise levels into two parts at the point at which the label "Exceeds Recommended Limits" is to be applied.
2. Estimate the mean of the "Redistributed" new products as being a few dB below the labeling limit (see Figure 3-12 (b)).
3. Estimate the standard deviation of this distribution as being less than the difference between the distribution mean and the labeling limit.
4. Estimate the fraction of new products which will be redesigned rather than be labeled "Exceeds Recommended Limits."

With this information, use the VESTA computer program to estimate the noise reduction for two to four different labeling limits. Pair the costs found above with these noise reductions to establish the cost function for this countermeasure.

3.4.16 Maintenance Standard

A local government may require a periodic maintenance check of certain products in order to reduce the high noise levels generated by products which are poorly maintained. Maintenance standards are recommended primarily for motor vehicles and could consist of a check-up every 1 to 4 years in connection with registration renewal. Costs to the city include administration and enforcement. Owners of products cited under the standard pay for any modifications which are needed. The noise reduction obtained with a maintenance standard depends on the particular maintenance requirement, the original number of out-of-spec products, and the percent of products which are modified to comply with the standard.

1. Costs

A. Annual Costs to the City

	$M_{A/E}$	Annual man-months required for administration/enforcement
x	C_E	Cost of employee, per month
x	D_1	Discount factor for year when annual costs to city begin
x	11	Discount factor to account for continuous annual future funding
=	ⓐ	Total annual costs to the city

B. One-Time Costs to Others

	C_A	Cost to operator of altering equipment, per piece
x	Q	Number of modified pieces of equipment
x	D_2	Discount factor for year when one-time costs to others occur
=	ⓑ	Total one-time costs to others

Total Costs of Countermeasure = ⓐ + ⓑ

Fraction of Costs Incurred by City = ⓐ ÷ (ⓑ + ⓐ)

2. Noise Reduction

Maintenance and retrofit equipment standards are similar, therefore the steps required to estimate the noise reduction obtained with either of these two measures are presented in one discussion below (refer to Figure 3-14).

Step 1. Estimate the Mean and Standard Deviation of Operational Noise Levels Presently Emitted by the Source Population

Step 2. Estimate the Fraction of the Source Population Which Would Be in Violation of the Standard if it Were Put Into Effect

Step 3. Estimate the Noise Level Which is Exceeded by All (or Nearly All) Violating Products

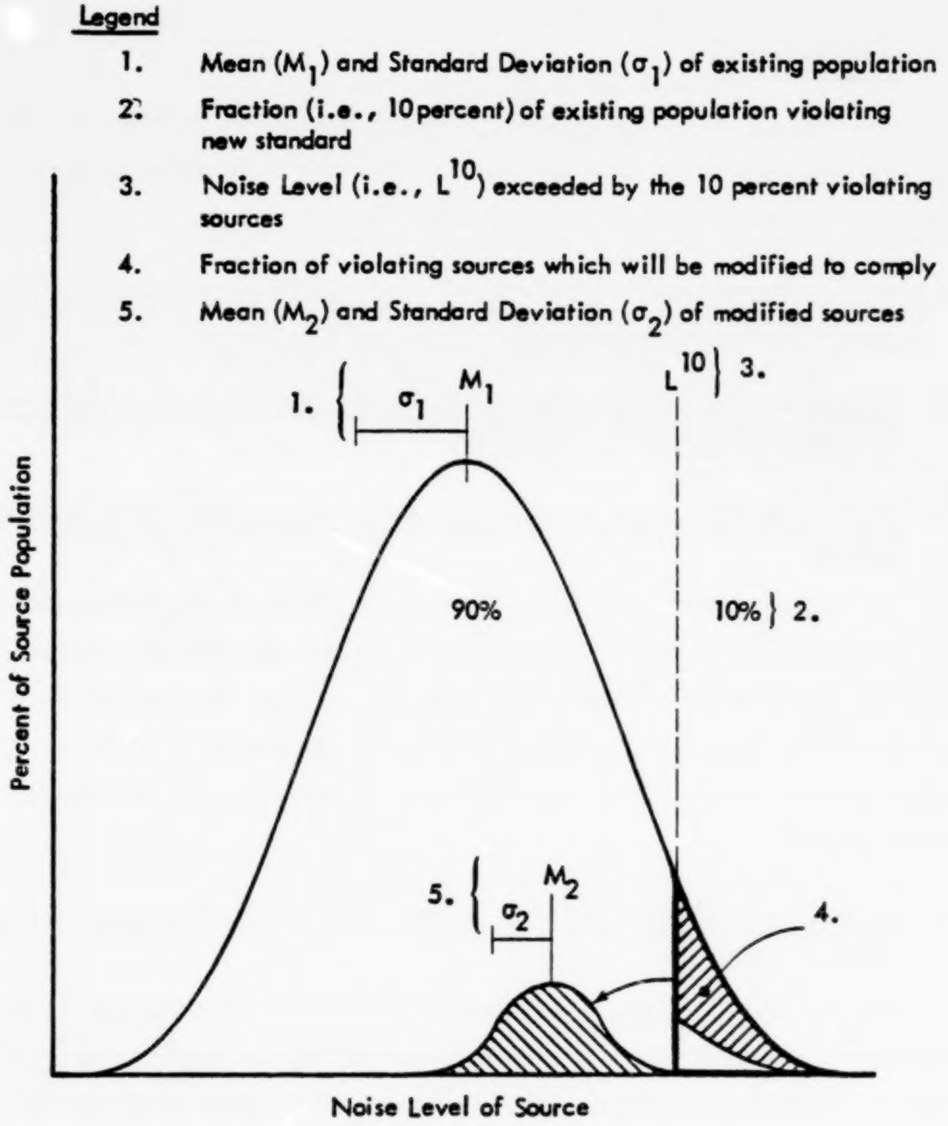
Assume that products in violation of the standard represent the noisiest portion of the source population. Thus, this fraction determines the exceeded noise level (see Figure 3-14). The noise level found in this manner may be symbolized in the general case by L^x, where x is the fraction of the population in violation of the standard. In the VESTA computer analysis which is to follow, use this level as the (hypothetical) "regulation level."

Step 4. Estimate the Fraction of Violating Products Which Will Be Modified as a Result of the Standard

This fraction will be highly dependent on the type of enforcement to be used. A yearly vehicle registration renewal requirement which includes a maintenance check may yield a compliance rate approaching 100 percent. On the other hand, if little or no education is provided to enforcement officers in regard to the standard, only a small fraction of product operators would comply.

Step 5. Estimate the Mean and Standard Deviation of the New Distribution of Vehicles Originally Poorly Maintained but Now Modified to Comply with the Standard

The mean may be expected to be substantially below the L^x in the case of a retrofit standard since a particular kind of replacement product is required. A lesser



Legend

1. Mean (M_1) and Standard Deviation (σ_1) of existing population
2. Fraction (i.e., 10 percent) of existing population violating new standard
3. Noise Level (i.e., L^{10}) exceeded by the 10 percent violating sources
4. Fraction of violating sources which will be modified to comply
5. Mean (M_2) and Standard Deviation (σ_2) of modified sources

1.
σ_1
M_1
L^{10}
3.
90%
10%
2.
5.
σ_2
M_2
4.
Percent of Source Population
Noise Level of Source

Figure 3-14. Items of Information Needed to Use the VESTA Computer Program

difference between the two levels is expected under a less strict "proper maintenance" standard since the owner would not be required to replace faulty noise equipment, but rather would tend to merely patch it up. In any case, for maintenance or retrofit standards applicable to modified or poorly maintained motor vehicles, a substantial (at least 5 to 10 dB) noise reduction can occur for individual vehicles. But since violating vehicles comprise only a small portion of the vehicle population, the overall noise reduction calculated in the next step is much smaller.

Step 6. Use the VESTA Computer Program

Using the information gathered above, operate the VESTA computer program to find the reduction in operational noise levels obtained with two to four different maintenance or retrofit abatement measures. Pair these results with the associated total costs to form the cost function.

3.4.17 Retrofit Standard

A retrofit standard requires that a particular type of replacement part must be added to a product if that product exceeds a specified noise limit. While a maintenance standard only requires that a product be properly maintained, a retrofit standard ensures that products producing excessive noise are treated with proper abatement devices, such as mufflers or shielding. Although differences exist, the methods of estimating the costs and noise reduction associated with these two measures are similar, and therefore the reader is referred to the discussion on Maintenance Standards (Section 3.4.16) for cost and noise reduction information.

3.4.18 Education

An educational campaign which is intended to reduce noise problems in the community can be directed at either the operators of noisy products, the people in charge of the products' operation, or the people who hear the noise but don't know what to do about it. (Educational programs directed at administrative or enforcement personnel do not directly reduce noise in the community, although in many cases they are a necessary adjunct to noise control in the community. Such programs are not considered here.) Educational campaigns may assume a wide variety of forms ranging from sending out a flyer to residents living near the site of an upcoming noisy construction project to once a week interviews with a noise control expert on TV or radio. Costs of these campaigns are usually borne by the local government, although funding from higher levels of government may be available. The noise reduction associated with a given campaign is extremely hard to estimate. Factors such as timing, media impact, and other concurrent issues in the community may make the difference between significant community involvement and no involvement at all. However, some initial guidelines are presented which indicate how noise reduction estimates may be made.

1. Costs

A. Annual Costs to the City

	$M_{A/E}$	Annual man-months of administration/enforcement
x	C_E	Cost of employee, per month
+	C_M	Cost of materials and media
x	D_1	Discount factor for year when annual costs to city begin
x	11	Discount factor to account for continuous annual future funding
=	ⓐ	Total annual costs to the city

B. Costs to Others

(see individual discussions under Noise Reduction below)

Total Cost of Countermeasure = ⓐ

Fraction of Costs Incurred by City = 1.0

2. Noise Reduction

In itself, the establishment of an educational campaign does not reduce community noise levels. However, it may cause changes in peoples' behavior which may result in a reduction of the noise being emitted either by the people themselves, or by the product which they are operating. There are many examples of such behavioral changes and their associated noise benefits, but there are few guidelines which can be provided for making estimates of the noise reductions involved since each case is likely to be unique to each community, highly dependent on nonacoustical factors, and slow to show long-term measurable differences. Nonetheless, the following specific examples of the effects of potential measures of this type may be used as guidelines in developing estimates of the costs and effects of your particular program. Example effects include:

1. Change in Operation of Noisy Products

As an example of this effect, if education convinces hot-rodders to reduce their hot-rodding, or if it initiates some citizen reaction against noisy vehicles, then this action is similar to that of Acceleration Controls, discussed in Section 3.4.2. The costs and noise reduction associates with this effect are similar to those discussed under Operational Controls (see Section 3.4.2).

2. Change in Area of Operation

Off-road motorcycle operators are asked to limit their activity to a particular piece of land. This would require some advertisement of the suggested operating locations, but would not necessarily involve a law. The costs and noise reduction of this effect are similar to those of Area Restrictions (Section 3.4.3).

3. Change in Time of Operation

A case where education might affect the time of operation would be if general aviation aircraft pilots are advised to limit the times when they fly to the hours between 7 a.m. and 10 p.m. The costs and noise reduction of this effect would then be similar to those of Time Restrictions (Section 3.4.4).

4. Increased Concern for Building Insulation

As a result of educating people about the adverse effects of noise, there may be increased concern for proper noise insulation of homes. If this concern causes improvements in initial construction practices, the educational program would be similar to a Building Code (Section 3.4.11) only without the administrative and enforcement cost components. If the concern causes people to modify existing homes, the program would be similar to a Building Insulation measure (Section 3.4.7), again without the associated administrative personnel requirements.

5. Reduced Sensitivity to Noise

Education is more likely to cause increased sensitivity of people to noise, not less. However, in some instances, if the people who are impacted by the noise are advised that the operators of the noise sources are doing all they can to reduce the noise – or, if the importance to the community of the noise source is properly advertised – then the sensitivity of impacted people may actually decrease. The costs (besides media costs) and the noise reductions involved in this approach would be similar to those of Compensation (Section 3.4.8).

6. Population and Source Relocation

One topic which an educational program might address is the noise levels existing in the community. If areas where excessive outdoor noise levels exist were pointed out to the community, people looking for a new home may decide to locate themselves in a quieter neighborhood than they would have if they had not known about the noise levels beforehand. In effect, there might be a volunteer type of Population Relocation (Section 3.4.9), again without extensive government participation. Similarly, if an industry was looking for a new place to locate a noisy operation, it would be in its own best interest to locate the operation in an area where either the noise levels were already high, or where there were few concerned residents. This type of information could easily be part of a community education effort. Costs and the associated noise reduction for such effort would be similar to those discussed under Planning and Zoning (Section 3.4.10), again without the administrative/enforcement costs involved.

7. Changes in Consumer Preference Patterns

An educational program aimed at consumers would highlight certain options which the public has in buying quieter products and in pressuring manufacturers to produce quieter produces. Such a change in consumer preferences would have effects similar to those discussed under the Labeling alternatives in Section 3.4.15.

8. Improved Maintenance of Products

A program which educated owners of certain products such as automobiles, lawn mowers, air conditioners, and the like, would emphasize the importance of keeping such products properly maintained so that the noise levels do not substantially increase as the product ages. The costs and effects of this type of program would be similar to those discussed under Maintenance Standards (Section 3.4.16) without the costs of governmental administration and enforcement.

3.4.19 Complaint Mechanism

Programs which are designed to provide governmental response to citizen complaints about a noise problem fall under the category of "Complaint Mechanism." An example would be a noise "hot line" which citizens could call and get rapid responses from enforcement officials trained in acoustical measurement techniques. Since a complaint response program may assume many different forms and result in a variety of noise control actions, no cost or noise reduction formulae are presented here specifically for this alternative. Rather, the reader is referred to related alternatives discussed above.

Almost all citizen complaint programs involve some administrative and enforcement costs on the part of the city. The resulting noise reduction is extremely difficult to predict, but it primarily occurs in one of two ways: (1) shifting the time during which the offending noise source is operated (including eliminating the operation); or (2) changing the manner in which the source is operated.

An example of the first type of effect due to citizen complaints is a change in the time from nighttime to daytime when quarry blasts are scheduled. If this type of effect is expected to occur as a result of establishing a complaint mechanism, define the costs and associated noise reduction by following the discussions under Time Restrictions (Section 3.4.4) above.

An example of the second type of effect is a reduction in the frequency of hot-rodding in quiet residential areas as a result of calls from annoyed citizens. The costs and noise reduction of such an effect are considered under Operational Controls (Section 3.4.2) above.

Note, however, for both of the above examples that governmental enforcement efforts (and the associated costs and degree of compliance) are a function of citizen involvement (complaints), whereas the efforts expended to enforce Time Restrictions and Operational Controls in the absence of a citizen complaint mechanism depend only on the amount of money and manpower the government is willing to expend.

Finally, it should be pointed out that communities which have aggressively pursued an enlightened and active program to encourage and act on noise complaints have found this to be an effective means for achieving positive results in terms of actual reduction in localized and specific community noise problems.

4.0 SELECTION OF OPTIMAL ACTIONS

4.1 Operate Noizop Program

The user of this manual should be familiar with the full Noizop User's Guide[3] and Appendix A of this manual before proceeding with this chapter. The remainder of this section briefly summarizes the basic procedures necessary to use the cost-effectiveness optimization model.

4.1.1 Assemble Input Data

A listing of the input data required for the operation of Noizop is given in Table 4-1 along with the corresponding section of this manual and the Noizop User's Guide in which they are discussed. Some references are made to Appendix A of this manual where the input data item is applicable to the enhanced version of Noizop created for this manual and is not discussed in the original User's Guide.

Most of the technical input data (i.e., noise levels, countermeasure definition, effectiveness, and costs) are developed in Chapters 2 and 3 of this manual. Miscellaneous specifications such as titles or option indicators are fully described in the Noizop User's Guide. A number of items have been supplied with default values as indicated by the footnotes in Table 4-1.

4.1.2 Obtain Output Results

The main output which Noizop provides is a list of total expenditures recommended for each abatement measure. The amount of expenditures for each measure depends on the total budget available. The recommended expenditures on each measure are displayed as the optimization process proceeds in discrete steps. At each step the total expenditure is broken down by costs to the local government ("User Costs") and costs to the rest of society ("Total Costs"). The total budget is thus society's budget, not the local government's budget. The costs at each budgetary step are accompanied by the associated Noise Impact Index (NII), which is a measure of the adverse effects of noise on people in the community. The NII is decreased in an optimal fashion as more and more money is allocated to the countermeasures.

Table 4-1

Summary of Input Data Required by Noizop

Noizop Input	Section Where Input is Discussed	
	This Manual	User's Guide 3
1. Whether or not an auxiliary print file is desired, and if so, the Fortran logical unit number.	—	2.0
2. A title for the data set.	—	2.0
3. A title for the job description.	—	2.0
4. Titles for sources and indicators.	—	2.1
5. Array of source contribution indices for the baseline index.	—	2.1
6. Input Data for Community Cells.		
a.(1) Disposition of echo input feature.	—	2.1
b. Whether or not constant indicators are being input.	—	2.1
c. Zone number.	3.3.1	2.1
d. Cell number (including day/night indicator).	3.3.1	2.1
e. Cell population.	3.3.2	2.1
f. Cost to relocate cell.	3.4.9	2.1
g. Floor area of each cell.	3.3.4	2.1
h.(2) Lower criterion level.	1.2, A.2.1	2.1, 2.7
i. Land use type.	3.3.4, A.2.1	2.1
j. L_d and L_n for up to 20 sources.	2.4, 3.3.3	2.1
k. Countermeasure indicators.	A.2.1	2.1, 2.2
7. Countermeasure Definitions.		
a. Countermeasure Title.	—	2.2
b. Countermeasure Type Number.	A.2.1	2.2
c. Affected Source Number(s).	—	2.2
d. Countermeasure Indicator Number(s)	—	2.2
8. Cost Functions for Countermeasures.		
a. Title for Cost Function.	—	2.3
b. Feasible Range of Countermeasure Variable.	3.4	2.3
c. Intermediate Values of the Countermeasure Variable and Corresponding Costs.	3.4	2.3
9. Path-Receiver Countermeasure Input Data.		
a. Soundproofing.		
(1) Title for soundproofing input.	—	2.5
(2) Path-Receiver countermeasure option override array	—	2.5
(3) Three decibel levels of soundproofing reduction and associated costs per square foot (residential).	3.4.7	2.5
(4) Like (3) for nonresidential.	3.4.7	2.5
b. Barriers.		
(1)(3) Disposition of nonexistent cell printout option.	—	2.4
(2) Title for barrier input.	—	2.4
(3) Barrier effectiveness ratios (high and low barriers).	3.4.6	2.4
(4) Barrier number.	—	2.4
(5) Cost of each high barrier.	3.4.6	2.4
(6) Cost of each low barrier.	3.4.6	2.4
(7) Primary cell identifier (zone and number).	3.4.6	2.4
(8) Barrier attenuation at primary cell (high and low).	3.4.6	2.4
(9) Secondary cell identifiers.	3.4.6	2.4
(10) Barrier attenuations at secondary cells (high and low).	3.4.6	2.4

Table 4-1 (Continued)

Noizap Input	Section Where Input is Discussed	
	Manual	User's Guide[3]
10. Stationary Source Countermeasure Input Data.		
a. Title for Countermeasure Data.	—	2.6
b. Stationary Source Countermeasure Option Override Array.	—	2.6
c. Stationary Source Number.	—	2.6
d. Minimum Source Level Reduction.	3.4.1	2.6
e. Maximum Source Level Reduction.	3.4.1	2.6
f. Cost of Minimum Reduction.	3.4.1	2.6
g. Cost of Maximum Reduction.	3.4.1	2.6
h. Cost to Eliminate Nighttime Operations.	3.4.4	2.6
i. Cost to Eliminate Source.	3.4.3	2.6
11.(4) Modifications to Response Functions.		
a. Criterion Levels.		
(1) Land use types affected.	3.3.4, A.2.1	2.1, 2.7
(2) Which levels to be changed (upper or lower).	A.2.1	2.7
(3) Criterion levels day and night.	1.2, A.2.1	2.1, 2.7
b. Transfer Functions.		
(1) Transfer function type number.	A.2.1	2.7
(2) Bulge factor.	A.2.1	2.7
12.(4) Data Factoring.		
a.(5) Disposition of cell by cell printout feature.	—	2.8
b. Data factoring title.	—	2.8
c. Land use types for which factors apply.	—	2.8
d. Zone numbers for which ratios apply.	—	2.8
e. Factors for source levels.	—	2.8
13. Input of User Cost Data ("Cost to City").		
a. User cost title.	A.2.1	—
b. User cost fractions for each countermeasure.	3.4, A.2.1	—
14. Attitudinal Adjustments for Source Levels.		
a. Disposition of cell by cell output feature.	A.2.1	—
b. Source level numbers.	3.3.3, A.2.1	—
c. Decibel adjustment value.	3.3.3, A.2.1	—
15. Base Index Calculation Option.	—	2.9
16. Source Ranking Calculation Option.	—	2.10
17. Optimization Procedure.		
a.(6) Disposition of path-receiver breakdown output option.	—	2.11
b.(7) Disposition of stationary source gradient calculation option.	—	2.11
c. Total budget.	4.1.2, 4.3	2.11
d.(8) Gradient stepsize.	A.2.1	2.11
e.(9) Initial maximum expenditure ratio.	—	2.11
f.(10) Expenditure retraction factor.	A.2.1	—
g.(11) Number of refinement stages.	A.2.1	—
h. Starting expenditures on each countermeasure.	—	2.11
18. Program Termination Card.	—	2.12

Table 4-1 (Continued)

Explanations to Footnotes

(1) Default = No Echo Input.

(2) Default Values Supplied. (See Table 1-1)

(3) Default = Program Terminates if Barrier Defined for Nonexistent Cell.

(4) No Inputs Required for this Section.

(5) Default = No Cell by Cell Output.

(6) Default = Output.

(7) Default = Approximations Are Used.

(8) Default Stepsize = 1/100 of Total Budget

(9) Default Ratio = 10.

(10) Default Retraction Factor = 1.0.

(11) Default Number of Refinement Stages = 0.

Figure 4-1 briefly illustrates this process. The initial expenditures were entered at zero and the optimization process continued until the total societal budget of $4.5 million was expended (not shown in this figure).

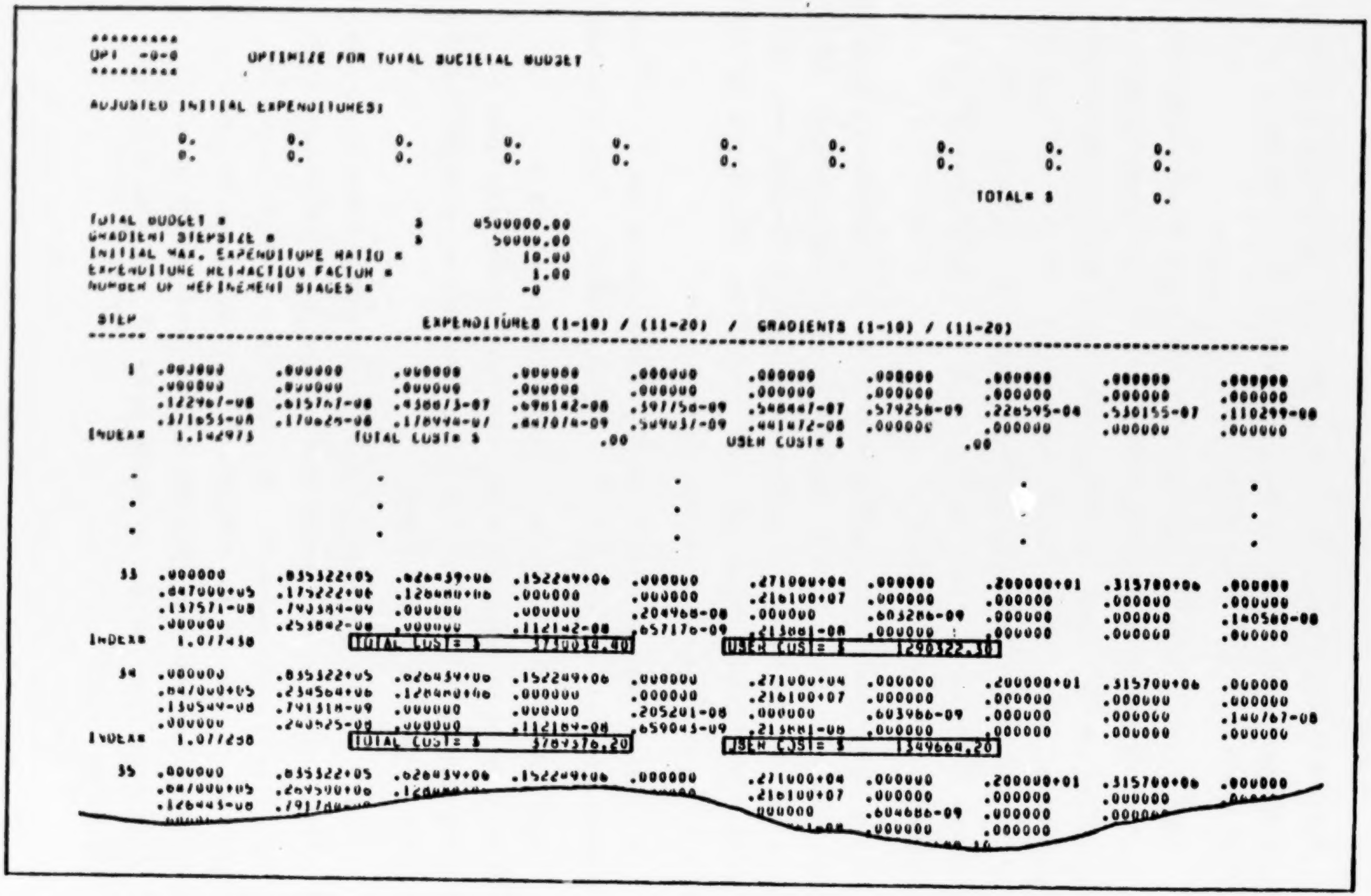
When the entire budget is expended, Noizop provides a complete breakdown of the final expenditures among the countermeasures. Therefore, to obtain a complete breakdown of the optimized countermeasure expenditures of a local government budget, run Noizop twice. The first time, increase the total budget to a value which is several times the amount which will be budgeted by the local government for noise control. In the example of Figure 4-1, a $4.5 million budget is specified; the hypothetical local government budget is $1.33 million.

Find the expenditure step at which the cost to the local government ("User Cost") is approximately equal to (just less than) the amount available from local funds. Note the individual costs allocated to each countermeasure and the total cost at this step. Use this total cost to estimate the total budget for a second Noizop run. Also note the individual expenditures on each of the countermeasures (the top two rows).

In Figure 4-1, the user budget of $1.33 million appears between Steps 33 and 34, corresponding to total societal budgets of $3.73 million and $3.79 million, respectively.

Figure 4-2 illustrates a hypothetical second Noizop run. The initial expenditures at the top of the figure are the same as those for Step 33 in Figure 4-1. It was estimated that a total societal budget of $3.75 million would yield the desired local government budget of $1.33 million.

Figure 4-2 also illustrates the refinement stage concept. When the procedure above the continuation dots was complete (total expenditures of $3.75 million), the expenditures on each countermeasure (one at a time) were retracted to zero and the optimization process continued from there until the $3.75 million was expended. In Figure 4-2, only the retraction of Countermeasure 2 is shown since retracting the expenditures on that countermeasure yielded the lowest NII. See Appendix A for a more complete discussion of this concept.



```
*********
OPT  -0-0        OPTIMIZE FOR TOTAL SOCIETAL BUDGET
*********

ADJUSTED INITIAL EXPENDITURES:

        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.        0.        0.
                                                                              TOTAL= $        0.

TOTAL BUDGET =                         $     4500000.00
GRADIENT STEPSIZE =                    $       50000.00
INITIAL MAX. EXPENDITURE RATIO =                  10.00
EXPENDITURE RETRACTION FACTOR =                    1.00
NUMBER OF REFINEMENT STAGES =                      -0

 STEP                       EXPENDITURES (1-10) / (11-20)  /  GRADIENTS (1-10) / (11-20)
------ -------------------------------------------------------------------------------------------

    1  .000000     .000000     .000000     .000000     .000000     .000000     .000000     .000000     .000000     .000000
       .000000     .000000     .000000     .000000     .000000     .000000     .000000     .000000     .000000     .000000
       .122967-08  .615767-08  .430673-07  .698142-08  .397756-09  .548447-07  .579256-09  .226595-08  .530155-07  .110299-08
       .371655-08  .170625-08  .178994-07  .847074-09  .549037-09  .441472-08  .000000     .000000     .000000     .000000
INDEX=   1.142973           TOTAL COST= $            .00           USER COST= $            .00

    .                    .                          .                                  .                    .
    .                    .                          .                                  .                    .
    .                    .                          .                                  .                    .

   33  .000000     .835322+05  .626439+06  .152249+06  .000000     .271000+04  .000000     .200000+01  .315700+06  .000000
       .847000+05  .175222+06  .128480+06  .000000     .000000     .216100+07  .000000     .000000     .000000     .000000
       .137571-08  .743384-09  .000000     .000000     .204968-08  .000000     .603286-09  .000000     .000000     .140580-08
       .000000     .253842-08  .000000     .112142-08  .657176-09  .213881-08  .000000     .000000     .000000     .000000
INDEX=   1.077430           TOTAL COST= $     3730034.40           USER COST= $     1290322.30

   34  .000000     .835322+05  .626439+06  .152249+06  .000000     .271000+04  .000000     .200000+01  .315700+06  .000000
       .847000+05  .234564+06  .128480+06  .000000     .000000     .216100+07  .000000     .000000     .000000     .000000
       .130549-08  .741318-09  .000000     .000000     .205201-08  .000000     .603966-09  .000000     .000000     .140767-08
       .000000     .240525-08  .000000     .112184-08  .659043-09  .213881-08  .000000     .000000     .000000     .000000
INDEX=   1.077250           TOTAL COST= $     3789376.20           USER COST= $     1349664.20

   35  .000000     .835322+05  .626434+06  .152249+06  .000000     .271000+04  .000000     .200000+01  .315700+06  .000000
       .847000+05  .269590+06  .128                                .216100+07  .000000     .000000     .000000
       .126443-08  .7917                                            000000     .604686-09  .000000     .0000
                                                                              .000000     .000000
```

Figure 4-1. Example Noizop Output During Optimization Process. Hypothetical User Budget of $1.33 million Lies Between a Total Societal Budget of $3.73 million and $3.79 million.

```
*********
OPT -0-0        OPTIMIZE FOR TOTAL SOCIETAL BUDGET
*********

ADJUSTED INITIAL EXPENDITURES:

      0.      83532.    626439.    152249.          0.      2710.         0.         2.    315700.         0.
  84700.     175222.    128480.         0.          0.   2161000.         0.         0.         0.         0.
                                                                                TOTAL= $    3730034.

TOTAL BUDGET =                        $     3750000.00
GRADIENT STEPSIZE =                   $       50000.00
INITIAL MAX. EXPENDITURE RATIO =                 10.00
EXPENDITURE RETRACTION FACTOR =                   1.00
NUMBER OF REFINEMENT STAGES =                     1

 STEP                          EXPENDITURES (1-10) / (11-20)  /  GRADIENTS (1-10) / (11-20)
------ -----------------------------------------------------------------------------------------------

   1  .000000     .835322+05  .626439+06  .152249+06  .000000    .271000+04  .000000    .200000+01  .315700+06  .000000
      .847000+05  .175222+06  .128480+06  .000000     .000000    .216100+07  .000000    .000000     .000000     .000000
      .137547-08  .740368-09  .000000     .000000     .204968-08 .000000     .603286-09 .000000     .000000     .140580-08
      .000000     .253842-08  .000000     .112142-08  .657176-09 .000000     .000000    .000000     .000000     .000000
INDEX=   1.077438            TOTAL COST= $   3730034.00           USER COST= $    1290322.10

  .            .                          .                                   .                        .
  .            .                          .                                   .                        .
  .            .                          .                                   .                        .

REFINEMENT STAGE NUMBER:   1

RETRACTING EXPENDITURE ON COUNTERMEASURE  2 TO ZERO

-------------------------------------------------------------------------------------------------------


ADJUSTED INITIAL EXPENDITURES:

      0.          0.    626439.    152249.          0.      2710.         0.         2.    315700.         0.
  84700.     195188.    128480.         0.          0.   2161000.         0.         0.         0.         0.
                                                                                TOTAL= $    3666468.

TOTAL BUDGET =                        $     3750000.00
GRADIENT STEPSIZE =                   $       50000.00
INITIAL MAX. EXPENDITURE RATIO =                 10.00
EXPENDITURE RETRACTION FACTOR =                   1.00
NUMBER OF REFINEMENT STAGES =                     1

 STEP                          EXPENDITURES (1-10) / (11-20)  /  GRADIENTS (1-10) / (11-20)
------ -----------------------------------------------------------------------------------------------

   1  .000000     .000000     .626439+06  .152249+06  .000000    .271000+04  .000000    .200000+01  .315700+06  .000000
      .847000+05  .195188+06  .128480+06  .000000     .000000    .216100+07  .000000    .000000     .000000     .000000
      .134795-08  .727443-08  .000000     .000000     .204641-08 .000000     .602553-09 .000000     .000000     .140324-08
      .000000     .248733-08  .000000     .112002-08  .656710-09 .000000     .000000    .000000     .000000     .000000
INDEX=   1.077778            TOTAL COST= $   3666467.80           USER COST= $    1289238.00

   2  .000000     .500000+05  .626439+06  .152249+06  .000000    .271000+04  .000000    .200000+01  .315700+06  .000000
      .847000+05  .195188+06  .128480+06  .000000     .000000    .216100+07  .000000    .000000     .000000     .000000
      .135095-08  .826311-09  .000000     .000000     .205061-08 .000000     .603286-09 .000000     .000000     .140650-08
      .000000     .249270-08  .000000     .112212-08  .658104-09 .000000     .000000    .000000     .000000     .000000
INDEX=   1.077414            TOTAL COST= $   3716467.80           USER COST= $    1301837.90

   3  .000000     .500000+05  .626439+06  .152249+06  .000000    .271000+04  .000000    .200000+01  .315700+06  .000000
      .847000+05  .220720+06  .128480+06  .000000     .000000    .216100+07  .000000    .000000     .000000     .000000
      .131225-08  .827244-09  .000000     .000000     .205131-08 .000000     .604220-09 .000000     .000000     .140767-08
      .000000     .242014-08  .000000     .112169-08  .658809-09 .000000     .000000    .000000     .000000     .000000
INDEX=   1.077530            TOTAL COST= $   3750000.00           USER COST= $    1335370.10
```

Figure 4-2. Example Noizop Output Illustrating Optimization of the User Budget Level of Expenditures. Input expenditures at top of figure are the same as those found in Step 33 in Figure 4-1.

At the bottom of Figure 4-2 is the final optimization step in our example. The final user cost was \$1.3354 million, very close to our target of \$1.33 million. The estimate of \$3.75 million total budget was a good one.

The "final expenditures" shown in the final step of Figure 4-2 are repeated and summarized in Figure 4-3. This Noizop output page presents the final results of the optimization process.

The "final countermeasure variables" indicate the extent to which each of the countermeasures should be implemented. The countermeasure variables are computed directly from the final expenditures using the cost functions that were defined. The countermeasure variables are either a decibel reduction or a fraction ranging between 0. and 1. that indicates the portion of a source population receiving a fixed decibel reduction treatment.

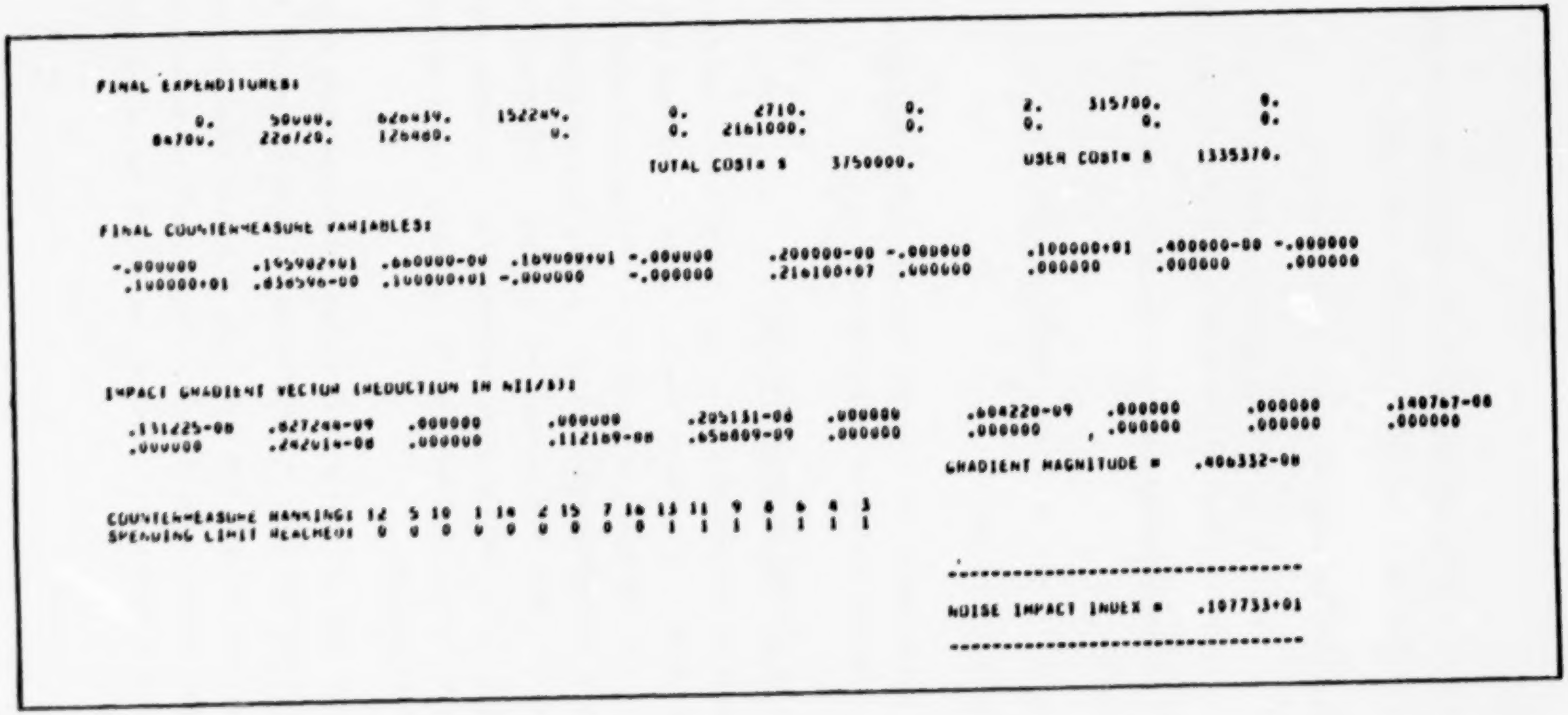
Not shown in Figure 4-3 is some additional results which Noizop presents, such as which barriers were selected to be built and which areas of the city should have building insulation.

A more complete discussion on how to interpret the Noizop output is included in the Noizop User's Guide.

4.2 Evaluate Output Results

At this point, the recommended expenditures and associated degree of implementation for each abatement measure should be checked to determine whether, in fact, they are feasible and practical. If the development of the cost functions described in Section 3.4 was performed with reasonable consideration for practical application, then the results should be readily applicable to a real-world noise control program. However, any additional political, social, or legal feasibility constraints not foreseen earlier should be considered at this time.

For instance, funding for building acoustic barriers may only be available in \$50,000 increments, or laws may require that expenditures on motor vehicles be



```
FINAL EXPENDITURES:

        0.     50000.    620439.    152249.        0.      2710.        0.        2.    315700.        0.
    84700.    220720.    126400.         0.        0.   2161000.        0.        0.         0.        0.
                                                   TOTAL COST= $   3750000.       USER COST= $   1335370.

FINAL COUNTERMEASURE VARIABLES:

 -.000000    .195902+01  .660000-00  .169000+01 -.000000    .200000-00 -.000000    .100000+01  .400000-00 -.000000
  .100000+01 .830596-00  .100000+01 -.000000    -.000000    .216100+07  .000000    .000000     .000000     .000000


IMPACT GRADIENT VECTOR (REDUCTION IN NII/$):

  .131225-08  .627244-09  .000000     .000000     .205131-08  .000000     .604220-09  .000000     .000000     .140767-08
  .000000     .242014-08  .000000     .112169-08  .658009-09  .000000     .000000   , .000000     .000000     .000000
                                                                          GRADIENT MAGNITUDE =   .406332-08

COUNTERMEASURE RANKING: 12  5 10  1 14  2 15  7 16 13 11  9  8  6  4  3
SPENDING LIMIT REACHED:  0  0  0  0  0  0  0  0  0  1  1  1  1  1  1  1


                                                                          --------------------------------

                                                                          NOISE IMPACT INDEX =   .107733+01

                                                                          --------------------------------
```

Figure 4-3. Example Results Page of Noizop Output. This figure completes the examples of Figures 4-1 and 4-2.

distributed in a certain way. If the expenditure recommendations cannot be adhered to, the procedure is to adjust one or more of the expenditure constraints:

- Raise or lower spending limits on each countermeasure.
- Alter the override arrays which prohibit certain countermeasures from being selected together (see Table 4-1, items 9a (2) and 10b).
- Add or remove countermeasures which should or should not be considered.
- Change the initial expenditures on each countermeasure.
- Modify the total budget.

Evaluate each of the above alternatives, make the necessary modifications to the Noizop input data, and operate the cost-effectiveness model again.

4.3 Select Final Set of Noise Abatement Measures

After a set of abatement measure expenditures has been selected which are acceptable and which can be implemented, it remains to determine the exact form which the measure will take. Some expenditure values will fall between values which were selected as potential expenditures when the cost functions were being formulated. For example, a regulatory level of 83 dB on trucks may have cost X dollars and a level of 80 dB may have cost Z dollars, but Noizop may recommend an intermediate expenditure of Y dollars. In cases such as this, find the appropriate regulatory level by interpolating between the nearest defined values.

The results of the cost-effectiveness optimization can be graphically presented in a number of ways. Several alternative possibilities are illustrated in Appendix A.

Figure 4-4 (the same as Figure A-4 in Appendix A) is printed directly by Noizop (the exact dollar amounts have been typed in). This histogram indicates the relative recommended expenditures on each of the countermeasures for both the total societal and user costs.

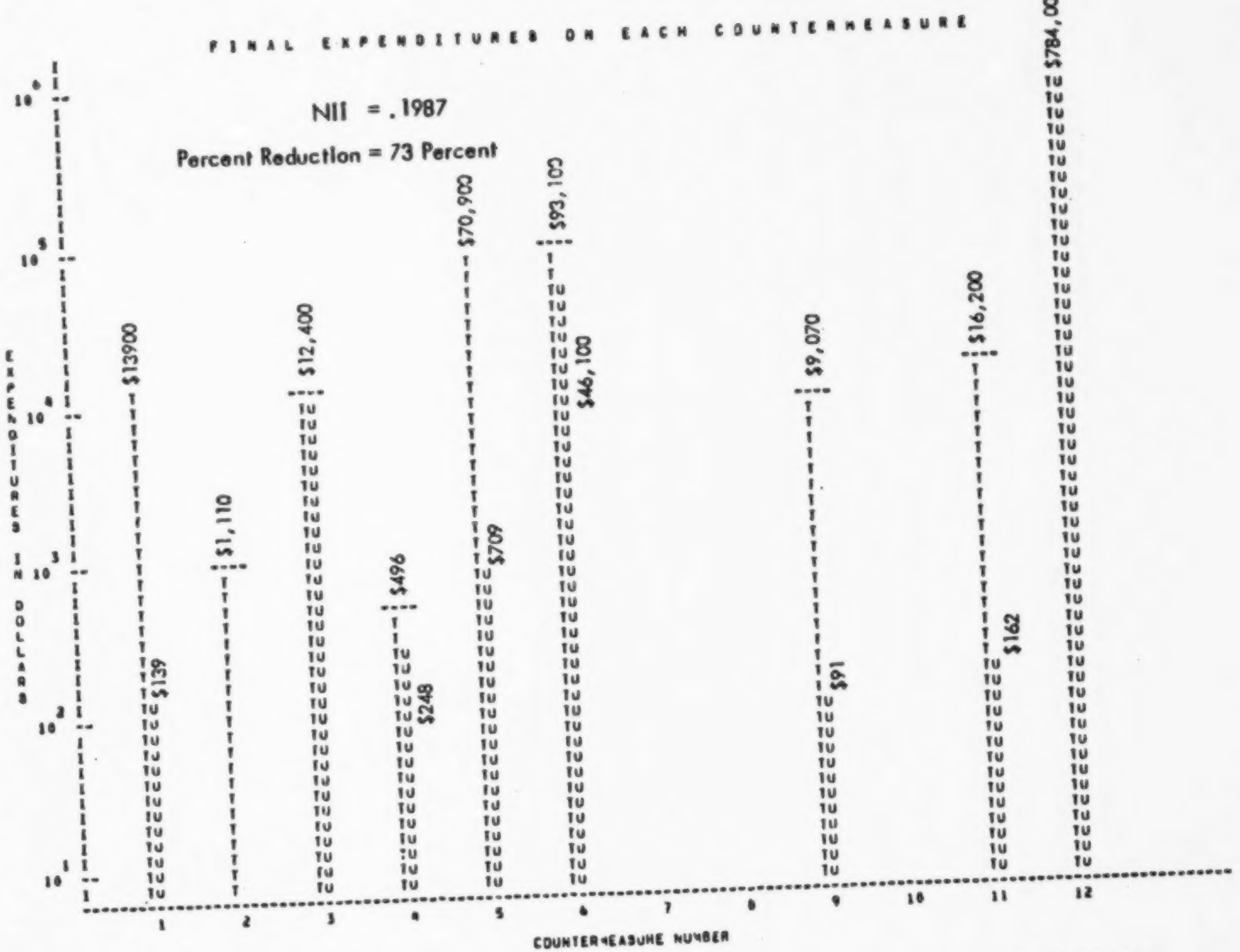


Figure 4-4. Baseline Case Optimization Results. T = Total Cost = $1,000,000; U = User Cost = $844,000.

Table 4-2 presents typical results in terms of the countermeasure variable, indicating recommended decibel reductions, fractions of source populations receiving fixed treatments, and dollar amounts to be spent on path-receiver countermeasures (barriers and soundproofing).

Section A.4 in Appendix A presents a brief discussion on the application of the procedures in this manual to a study of Allentown, Pennsylvania. This presentation can serve to partially illustrate the form and contents of a noise abatement measure assessment report. Each countermeasure is described and the results are shown in Table A A-9 indicating the relative cost-effectiveness of each. A discussion of the results of the computer analysis for each countermeasure follows. Figure A-16 presents a sequential diagram of the effectiveness of each level of expenditure on improving the noise climate of the community (quantified by the Noise Impact Index). This signifies that, after a certain point, the cost-effectiveness of each additional expenditure is drastically reduced. This result might be applied to the concept and definition of an "optimal total budget."

Table 4-2

Extent of Countermeasure Application to the Six Hypothetical Examples. The Countermeasure Application Corresponds to Total Expenditures on Each Countermeasure as Seen in Figures A-4 through A-7, A-10 and A-11

	Case					
Countermeasure	1 Baseline	2 Twice Residential Population Density	3 Community One-Half Site	4 Removing Motorcycle Source and Countermeasure	5 No Path-Receiver Countermeasure, Smaller Budget	6 No Attitudinal Adjustments
1. Percent of Automobiles Receiving 3.5 dB Reduction*	16%	19%	1%	13%	0	20%
2. Percent of Automobiles Receiving 3.5 dB Reduction*	57%	57%	57%	57%	57%	57%
3. Decibel Reduction in Automobile L_{eq} due to Enforcement of Ordinance	6.2 dB	6.2 dB	6.2 dB	6.2 dB	5.9 dB	6.2 dB
4. Decibel Reduction in Motorcycle L_{eq} due to Enforcement of Ordinance	17 dB	17 dB	17 dB	___**	17 dB	17 dB
5. Percent of Trucks Receiving 12 dB Engine Noise Reduction	36%	36%	36%	36%	25%	36%
6. Percent of Trucks Receiving 5 dB Tire Noise Reduction	100%	100%	100%	100%	33%	100%
7. Decibel Reduction in Bus L_{eq}	0	0	0	5.1 dB	0	0
8. Percent of Aircraft Receiving SAM Treatment	0	0	0	0	0	0
9. Percent of Aircraft Rerouted	100%	100%	100%	100%	100%	100%
10. Percent of Aircraft Night Operations Eliminated	0	0	0	0	0	0
11. Percent of Railroad Locomotives Receiving 6 dB Muffler Treatment	100%	100%	100%	100%	100%	100%
12. Total Dollar Expenditure on Barriers and Soundproofing	$784,000	$775,000	$791,000	$775,000	___**	$773,000

*Countermeasures 1 and 2 are mutually exclusive (Countermeasure Type 6). Countermeasure 1 applies to new vehicles, Countermeasure 2 applies to existing vehicles.

**Countermeasure not defined.

REFERENCES

1. Wyle Laboratories, "Community Noise Assessment Manual – Social Survey Workbook," Wyle Research Report WR 77-4, for the U.S. Environmental Protection Agency, July 1978.

2. Wyle Laboratories, "Community Noise Assessment Manual – Acoustical Survey," Wyle Research Report WR 77-17 for the U.S. Environmental Protection Agency.

3. Glenn, P.K., "Community Noise Countermeasures Cost-Effectiveness Computer Program (Noizop)," Wyle Research Report WCR 76-15, Volumes I-III, prepared for the Motor Vehicle Manufacturers Association, Inc., June 1977.

4. U.S. Environmental Protection Agency, "Information on Levels of Environmental Noise Requisite to Protect the Public Health and Welfare with an Adequate Margin of Safety," EPA Report No. 550/9-74-004, March 1974.

5. Galloway, W.J., Eldred, K. McK., and Simpson, M.A., "Population Distribution of the United States as a Function of Outdoor Noise Level," EPA Report No. 550/9-74-009, June 1974.

6. Rackl, R., Sutherland, L., and Swing, J., "Community Noise Countermeasures Cost-Effectiveness Analysis," Wyle Research Report WCR 75-2, for the Motor Vehicle Manufacturers Association, July 1975.

7. Schultz, T.J., "Synthesis of Social Surveys on Noise Annoyance," J. Acoust. Soc. Am., 64 (2), August 1978.

8. Szalai, A. (Ed.), "The Use of Time – Daily Activities of Urban and Suburban Populations in Twelve Countries" (Mouton Press, The Hague, 1972).

9. Bury, K.V., "Statistical Models in Applied Science" (John Wiley & Sons, Inc., New York, 1975).

10. Nelson, Jon P., "The Effects of Mobile Source Air and Noise Pollution on Residential Property Values," U.S. Department of Transportation Report No. DOT-TST-75-76, April 1975.

11. Ellwood, L.W., Ellwood Tables for Real Estate Appraising and Financing, 3rd ed. (Chicago, American Institute of Real Estate Appraisers, 1974).

12. "Financial and Business Statistics: Consumer and Wholesale Prices," Federal Reserve Bulletin, 63 (7), July 1977.

REFERENCES (Continued)

13. Burke, R.E., Bush, S.A., and Thompson, J.W., "Noise Emission Standards for Buses — An Environmental Impact Statement," Wyle Research Report WR 76-21 for the U.S. Environmental Protection Agency, November 1976.

14. "Construction Delays Costing Developers (and Public) Thousands," The Appraiser, January 1976.

15. "Basic User's Guide for the Integrated Noise Model, Version 1," FAA-EQ-78-01, December 1977.

16. Sharp, B.H., Plotkin, K.J., Glenn, P.K., and Slone, R.M., "A Manual for the Review of Highway Noise Impact," EPA Report No. 550/9-77-356, May 1977.

17. Davy, B.A. and Skale, S.R., "Insulation of Buildings Against Highway Noise," Wyle Research Report 76-10 for the U.S. Department of Transportation, Federal Highway Administration, November 1976.

18. Wyle Laboratories, "Measurement of the Noise Reduction of Acoustically Treated Classrooms at Schools in the Vicinity of Los Angeles International Airport," prepared for Willis K. Hutchason and Associates, December 1970.

19. Hutchason, Willis K. and Associates, "Aircraft Sound Attenuation of Classrooms," prepared for the City of Los Angeles (Department of Airports) and Schools Districts of Centinela Valley, El Segundo, Inglewood, and Lennox, 1971.

20. Sutherland, L.C., "Cost of Residential Noise Reduction Treatment – An Update of LAX Study," Wyle Technical Note 76-1, January 1976.

21. Wyle Laboratories, "Home Soundproofing Pilot Project," Wyle Research Report WCR 70-1, prepared for the Los Angeles Department of Airports, March 1970.

22. Federal Aviation Administration, "FAR Part 36 Compliance Regulation – Final Environmental Impact Statement," November 1976.

23. DeVany, A.S., "Benefits of Noise Abatement," unpublished paper for the National Academy of Sciences, June 1976.

24. Gamble, H.B., et al, "The Influence of Highway Environmental Effects on Residential Property Values," University Park, Pennsylvania, Institute for Research on Land and Water Resource, Pennsylvania State University, April 1974.

25. Personal Communication with Spokesman for the Golden West Insulation Company, Compton, California, February 2, 1978.

REFERENCES (Continued)

26. Glenn, P. K., "Community Noise Assessment Manual - Acoustical Survey Computerized Data Reduction Procedures," Wyle Research Report WR 79-8, for Computer Sciences Corporation, April 1979.

APPENDIX A

NOISE ABATEMENT OPTIMIZATION PROGRAM

A.1 Introduction

This appendix provides a brief technical description of the Community Noise Countermeasure Cost-Effectiveness Computer Program (called Noizop).* A summary statement appears below.

The acoustic environment of a community is modeled by the definition of small acoustically homogeneous divisions called cells. The source noise levels from up to 20 moving or stationary noise sources can be specified at each of up to 200 cell locations. The user may define up to 20 countermeasures (noise reduction options) selected from an available list of eight alternate general approaches to abate the noise sources. Additional input consists of the effectiveness and implementation costs for each of the defined countermeasures. The program calculates a single number evaluation of the noise climate in the community called the Noise Impact Index (NII) which is equivalent to the fraction of people in the community who would consider noise to be a significant detriment to their environment. The NII is the objective function which Noizop will seek to minimize using nonlinear optimization techniques. Constraining factors include feasible implementation (expenditure) limits on each countermeasure as well as a total budget for all countermeasures together. The end result is an optimum solution set for expenditure allocation among the countermeasures.

For the preparation of this strategy manual, an earlier version of Noizop was modified and enhanced to provide a tool suitable for use by local governments. The earlier program was referred to as version 2.1. The current version, described herein, is numbered 2.2. Both versions are in ANSI Standard FORTRAN IV.

Section A.2 describes each of the modifications associated with this new version of Noizop and serves as an update to the User's and Programmer's Guides associated with the original version.*

---

*Glenn, P.K., "Community Noise Countermeasures Cost Effectiveness Optimization Computer Program (Noizop)," Wyle Research Report WCR 76-15, Volumes I-III, for the Motor Vehicle Manufacturers Association, Inc., June 1977.

Section A.3 illustrates six hypothetical applications of Noizop on an actual Northern California community. Although these results are test cases and are not intended for implementation, they serve as a partial illustration of the range of potential uses of Noizop by local city governments and planning agencies.

Section A.4 is an application of Noizop to Allentown, Pennsylvania. This application, following directly from the procedures described in earlier sections of this manual, was performed to provide city officials of Allentown with an optimal noise abatement planning strategy.

A.2 Updates to the User's Guide and Programmer's Guide

A.2.1 User's Guide Updates

To furnish a computer utility suitable for local governments and planning agencies, several enhancements and updates were made to the existing version of Noizop. The following discussion describes all additions and modifications that have been made to the program. Table A-1 summarizes these changes. Parenthetical references are made to section numbers of the User's Guide where the related material is discussed. In the following discussion it is assumed that the reader is familiar with the Noizop User's Guide.[3]

1. Criterion Level Specification

Lower criterion levels (zero percent adverse response) which previously needed to be input with each cell have been given default values. These default values are listed in Table A-2.* The user may now leave a blank data field for the lower criterion level specification on the appropriate input data card (Section 2.1).

In addition, the default upper criterion levels (100 percent adverse response) have been revised to agree with EPA-recommended levels (Section 2.7). These are also listed in Table A-2.

---

*The default values specified are best estimates and have intentionally not been rounded to the nearest 5 dB which would ordinarily be done to reflect a more realistic measure of accuracy. The user can effect such a rounding if desired.

Table A-1

Additions and Modifications to Noizop as Defined in Reference 3

Addition or Modification	Related Section(s) in User's Guide
1. Criterion Level Specification	2.1, 2.7
2. Countermeasure Type Numbers	2.2
3. Countermeasure Indicators	2.2
4. Default Transfer Function	2.7
5. Input of User Cost Portions	New Addition
6. Attitudinal Source Level Adjustments	New Addition
7. Gradient Stepsize	2.11.1
8. Optimization Process	2.11
9. Output of Bar Graph Summarizing Results	New Addition

Table A-2

Default Criterion Levels
(Tables 2-2 and 2-7 in Reference 3)

Land Use Code	Suggested Usage	Default Lower Criterion Levels (0% adverse response, dB		Default Upper Criterion Levels (100% adverse response, dB)	
		Day	Night	Day	Night
1	Single and Two-family Residential	54	46	74	66
2	Open for Additional Residential Use	54	46	74	66
3	Single, Two, and Multifamily Residential	54	46	74	66
4	Multifamily Residential	59	46	79	66
5	Business and Commercial	59	59	79	79
6	Wholesale and Warehousing	59	59	79	79
7	Central Business District	59	59	79	79
8	Industrial	70	70	90	90
9	Public and Semi-public Areas	None	None	None	None
10	Parks	55	—	75	—
11	Schools	55	—	75	—
12	Hospitals and Nursing Homes	50	50	70	70
13	Open	None	None	None	None
14	Open	None	None	None	None
15	Open	None	None	None	None

2. Countermeasure Type Numbers

The countermeasure type numbers have been redefined in order to simplify the notation used in the previous version (Section 2.2). Table A-3 lists the old and new countermeasure type numbers. The user should use the new type numbers on the countermeasure definition data cards.

Table A-3

Countermeasure Type Numbers

Type Number		
Old	New	Countermeasure Definition
1	1	A reduction in the frequency of operation of the noise source. The fractional reduction is the same during the day and at night
3	2	A reduction in the frequency of nighttime operation of the noise source.
5	3	A shifting of the nighttime activity into the daytime period, or vice versa.
10	4	Application of a device that produces a fixed L_{eq} reduction to a portion of the source population.
12	5	An overall L_{eq} reduction.
15	6	Like 4, except that no further modifications are allowed to the treated portion of the source population.
18	7	Stationary source countermeasures.
20	8	Path or receiver modifications.

3. Countermeasure Indicators

Countermeasure types with new numbers 4 and 6 (see Table A-3) require countermeasure manipulation indicators to be defined (Section 2.2). The original version of Noizop permitted decibel reduction values which comprise the indicator to be entered to an accuracy no better than 0.5 dB. For local government application the definition of the indicator has been altered to allow entry of decibel reduction values accurate to 0.1 dB. The new definition of the indicator (I) is:

$$I = (dB1 \times 10 + 200) \times 1000 + (dB2 \times 10 + 200)$$

where

dB1 = maximum decibel reduction at the cell location for this countermeasure or the primary noise source.

dB2 = maximum decibel reduction at the cell location for this countermeasure on the secondary noise source.

Note that the maximum range of the decibel reductions have been reduced from ±100 dB to ±20 dB.

4. Default Transfer Function

The default transfer function is now linear allowing a value greater than 100 percent adverse response (Section 2.7). The previous default transfer function was also linear but did not allow a value greater than 100 percent adverse response. This change eas accomplished by giving the bulge parameter (Section 2.7) a default value of 1.

5. Input of User Cost Portions

A feature has been added which allows the user to specify the fraction of the costs for a countermeasure which the local government bears. Total costs for a countermeasure are still comprehensive societal costs and these costs still form the basis for the optimization. An additional codeword is now allowed - USER - which is used to enter the cost fractions. The first card following the USER codeword is a title card which may contain any pertinent information. The first 72 columns of the card may be used. The second (also the last) succeeding data card contains the countermeasure cost fractions (i.e., between 0. and 1.). The input format for this card is 20F4.0. The first field (columns 1 through 4) contains the fraction for countermeasure number 1, the tenth field (columns 37-40) contains the fraction for countermeasure number 10, etc. The default values for the user cost fractions are all unity, 1. Default values for user cost portions are initiated by not implementing the USER codeword.

The local government budget for noise abatement measures may be considerably less than the total societal budget. The user may determine the optimum disposition of the countermeasures at the user budget level by finding the optimization procedure step in the computer output which shows expenditure of a user cost value equal to the local government budget. The total user cost is printed along with the total societal cost for every step. Again, note that the countermeasures are optimized for the total cost rather than the user cost.

6. Attitudinal Source Level Adjustments

The capability to modify source noise levels for attitudinal biases has been added. The formula for making the adjustment is shown below.

$$L_{eq}\,(\text{new}) = L_{eq}\,(\text{old}) - \text{Corr}$$

The parameter in the above expression, Corr, is input to the program through the use of a new codeword, CORR. The CORR codeword allows an option parameter, a nonzero number in column 6 of the codeword card, which will cause a formatted listing of the main cell data to be printed showing the modified source levels. This printout option is the same option included with the DTA and FAC codewords (Sections 2.1 and 2.8, respectively).

The first data card following the codeword card is a title card of which the first 72 columns may be used. The succeeding data cards have the format as follows:

Field Number	Format	Data Item
1	I5	Noise Source Number
2	F5.0	Corr Value for this Source, dB

One card is required for each source receiving an attitudinal adjustment. A blank data card must follow the last adjustment data card to return control to the main program.

Note that the adjustment value, Corr, is subtracted from the source levels. Consequently, negative adjustments will increase the effective source levels while positive adjustments will decrease them.

Noizop will print the following diagnostic message if an invalid noise source number (greater than 20) is placed in field number 1 above.

INVALID SOURCE NUMBER IN ATTITUDINAL ADJUSTMENTS

This message will be printed identically in both the main and auxiliary print files.

7. Gradient Stepsize

The gradient stepsize (Section 2.11.1) is given a default value, initiated by a blank field on the appropriate data card, of the total specified budget divided by 100.; not $10,000 as mentioned in the User's Guide.

8. Enhancement of Optimization Process

This discussion complements and updates Section 2.11 of the Noizop User's Guide.

Because of a potential manyfold increase in the volume of output that is produced, the "I" option parameter now controls the printing of the results after each of the steps in the optimization procedure. The options are described, as listed in Table A-4, by the first option parameter for the codeword OPT.

The input data card containing the optimization control parameters now contains five parameters. The format is 4F10.0, I10:

1. The total budget
2. The gradient stepsize
3. The initial maximum expenditure ratio
4. The expenditure retraction factor
5. The number of refinement stages

Table A-4

First Option Parameter for OPT Codeword

Parameter Value	Effect
-1	Suppresses the printing of each of the steps in the optimization procedure from the main print as well as the auxiliary output file. Only the input expenditures and optimization control parameters are printed. No breakdown of path-receiver measures by cell location is given.
0	This is the default value. All steps in the optimization procedure are printed in both the main and auxiliary output files. A breakdown of path-receiver measures by cell location is provided.
1	Suppress the printing of each of the steps in the optimization process in the main print file. The abbreviated form is still provided in the auxiliary output file. No breakdown of path-receiver measures by cell location is given.

Parameters 1-3 are described in the Noizop User's Guide. The use of parameters 4 and 5 is explained in the following discussion.

In some instances, the steepest descent path optimization procedure may prove inadequate. This is due to the fact that the gradient testing method is somewhat shortsighted. That is, it determines the optimum point at a short distance (the gradient stepsize) from its current position. In so doing, it commits an expenditure to a countermeasure that it cannot retract. It may turn out that as the total expenditure increases, a new optimum point is established which involves reducing the expenditure on a countermeasure below that previously committed to reach an optimum earlier in the step-by-step optimization process. The previous version of Noizop would fail to find this new optimum point in such and instance because it did not allow retraction of expenditures on any countermeasure.

The operating theory of Noizop version 2.2 to correct this potential problem is illustrated in Figure A-1.

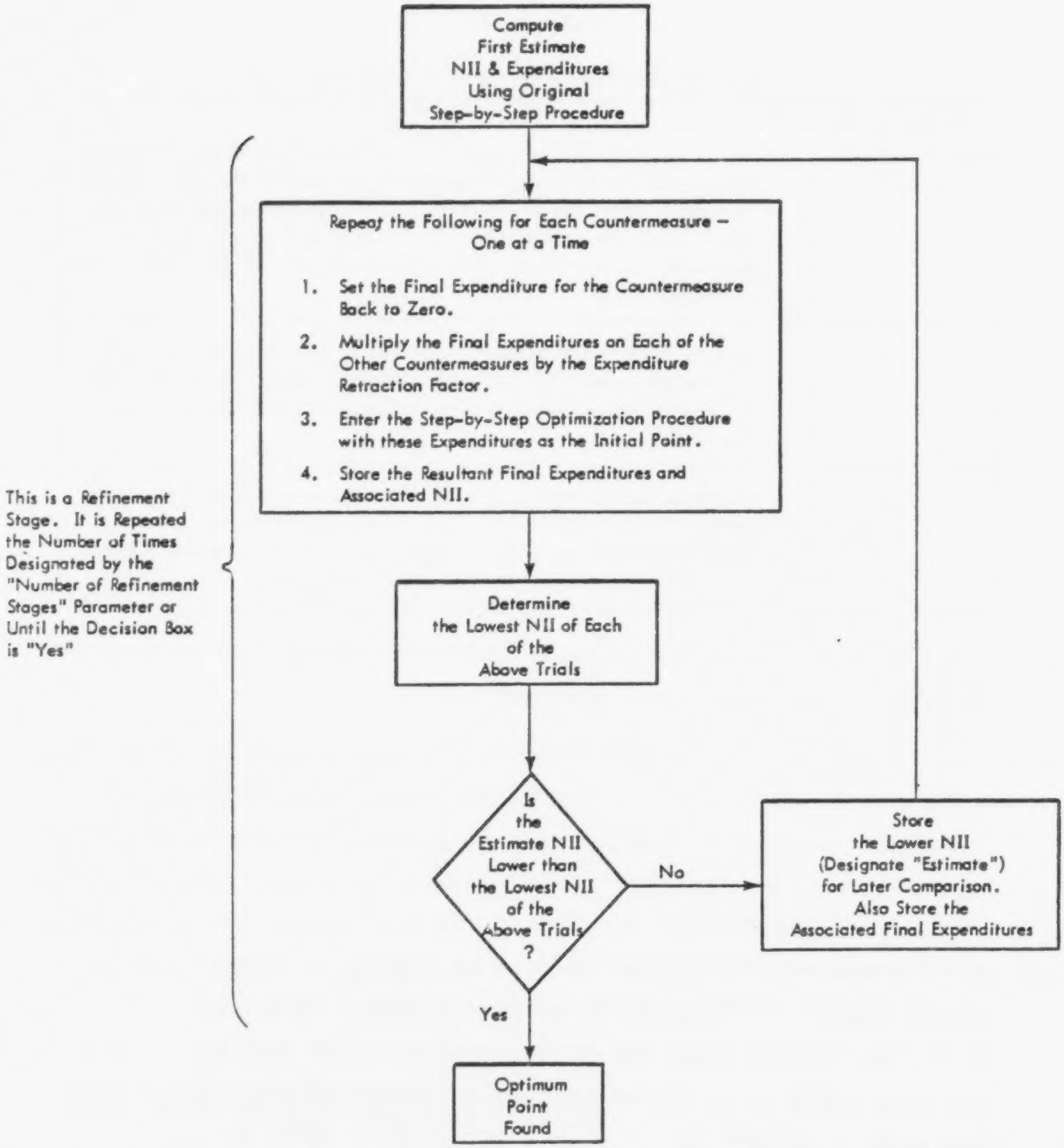

Compute First Estimate NII & Expenditures Using Original Step-by-Step Procedure
Repeat the Following for Each Countermeasure — One at a Time
1. Set the Final Expenditure for the Countermeasure Back to Zero.
2. Multiply the Final Expenditures on Each of the Other Countermeasures by the Expenditure Retraction Factor.
3. Enter the Step-by-Step Optimization Procedure with these Expenditures as the Initial Point.
4. Store the Resultant Final Expenditures and Associated NII.
This is a Refinement Stage. It is Repeated the Number of Times Designated by the "Number of Refinement Stages" Parameter or Until the Decision Box is "Yes"
Determine the Lowest NII of Each of the Above Trials
Is the Estimate NII Lower than the Lowest NII of the Above Trials ?
No
Store the Lower NII (Designate "Estimate") for Later Comparison. Also Store the Associated Final Expenditures
Yes
Optimum Point Found

Figure A-1. Functional Flow Diagram Describing Optimization Refinement Stages (Subroutine SEARCH)

As can be seen from Figure A-1, a quantity called the expenditure retraction factor is used to adjust the estimated final expenditures on each of the other countermeasures at the time when one of them is being retracted to zero. A factor less than 1. will reduce the values, a factor greater than 1. will increase them. The default value for this parameter, initiated by a blank field or a zero, is 1. which means that the expenditure values are not altered.

The "number of refinement stages" parameter controls the maximum number of times the expenditures on each countermeasure will be retracted to zero in search of a lower NII. The process will stop automatically in the event that a refinement stage fails to improve on the best value found in the previous refinement stage. The default value for this parameter, initiated by a blank field or a zero, is zero, no refinement stages. With no refinement stages, the results of this version (2.2) of Noizop will be identical to the results of the earlier (2.1) version.

9. Output of Bar Graph Summarizing Results

A bar graph is now produced which graphically illustrates the final expenditures on each of the countermeasures. Both total costs (T) and user costs (U) are plotted. Due to the extreme range of dollar values which may be expended, the expenditures axis is on a logarithmic scale. Care should thus be taken in reading this chart due to the nonlinear nature of the scaling. The chart is self-adjusting on both axes; that is, it will compute the range of values that are to be plotted and allow the maximum number of print positions to display the information. A horizontal line at the top of the bar for a countermeasure indicates the spending limit was reached on that countermeasure.

A.2.2 Programmer's Guide Updates

This section updates the Noizop Programmer's Guide to reflect the changes to the program described in the preceding section. (Figure numbers referred to indicate figures in the Programmer's Guide.)

Figure B-1 should show two new paths coming from the main program to describe the subroutine linkage for each of the two new codewords. For codeword USER, the subroutine that is called is named USERRD. For codeword CORR, the subroutine is named ATTCOR. The corrected figure is shown in Figure A-2.

Figure B-2 should indicate the calling levels of the new subroutines, SEARCH, BARGPH, and UFRAC. SEARCH is called directly by the main program (NOIZOP) and controls the manner in which OPTIM, the subroutine which performs the step-by-step optimization, is called. The operation of subroutine SEARCH is illustrated in Figure A-1. The annotated program listing should be consulted for a detailed description of the new subroutines. The corrected Figure B-2 is shown in Figure A-3.

A new COMMON block was added to contain the user cost fractions for each of the 20 possible countermeasures

/CMFRAC/ DIST (20)

Another new COMMON block contains the two new optimization parameters

/PRINT/FRED, NIT

- FRED is the expenditure retraction factor.
- NIT is the number of refinement stages.

A.3 Quantification of Model for Six Sets of Hypothetical Applications

This section describes the application of Noizop to six sets of alternate input data. These cases serve to partially illustrate the application of Noizop to communities of different characteristics and, at the same time, demonstrate the level of sensitivity of optimum countermeasure application to various communities.

The base data that was used represents the quantification of an actual Northern California community. Six cases were derived as variants of that data. They are summarized in Table A-5. Figures A-4 through A-11 and Table A-7 summarize the computer output for the six cases.

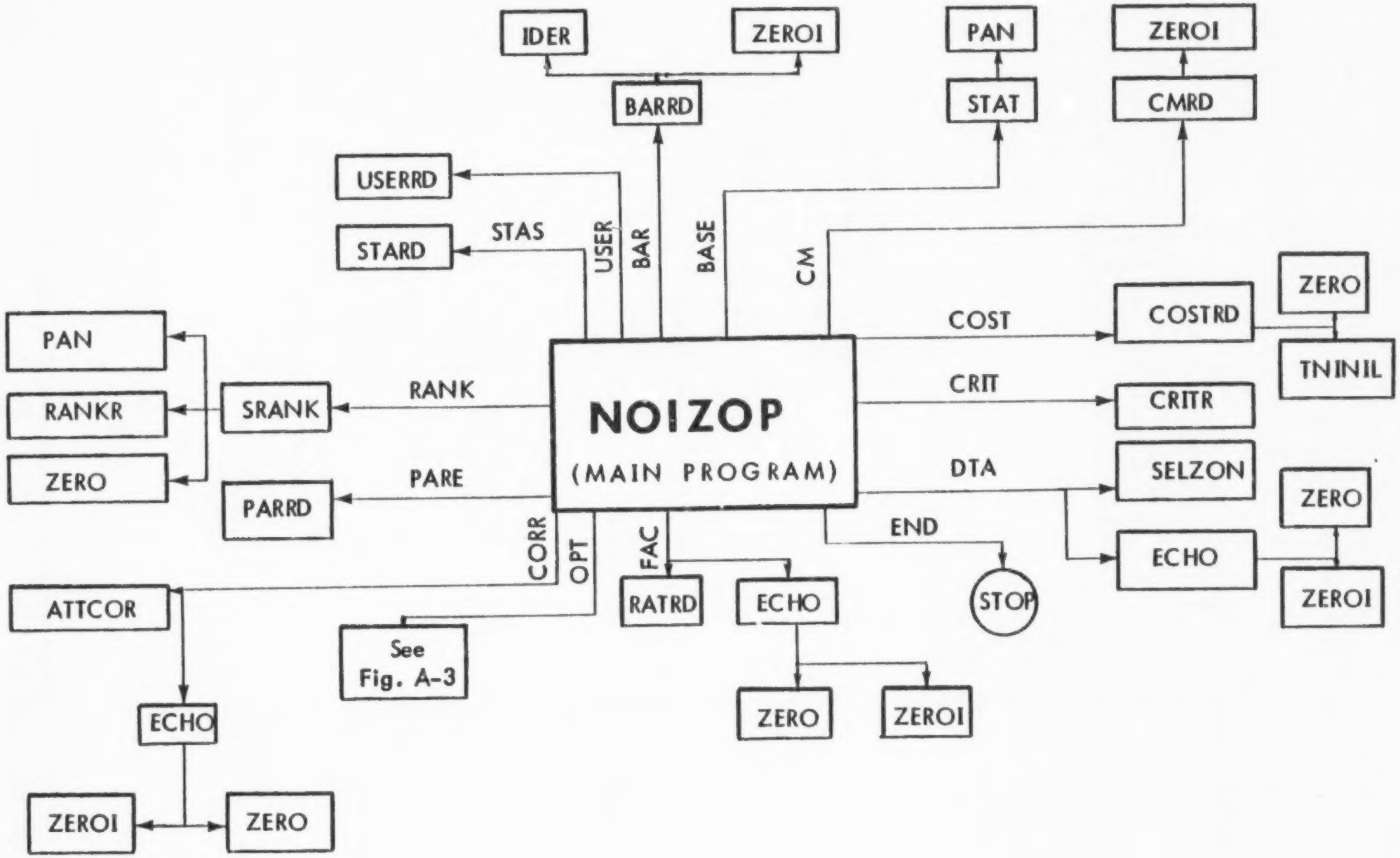

IDER
ZEROI
BARRD
PAN
STAT
ZEROI
CMRD
USERRD
STARD
STAS
USER
BAR
BASE
CM
COST
COSTRD
ZERO
TNINIL
PAN
RANKR
ZERO
SRANK
RANK
NOIZOP
(MAIN PROGRAM)
CRIT
CRITR
DTA
SELZON
PARRD
PARE
CORR
OPT
FAC
END
ZERO
ECHO
ZEROI
ATTCOR
See Fig. A-3
RATRD
ECHO
STOP
ZERO
ZEROI
ECHO
ZEROI
ZERO

Figure A-2. Subroutine Linkage Diagram Indicating Program Flow by Code Word

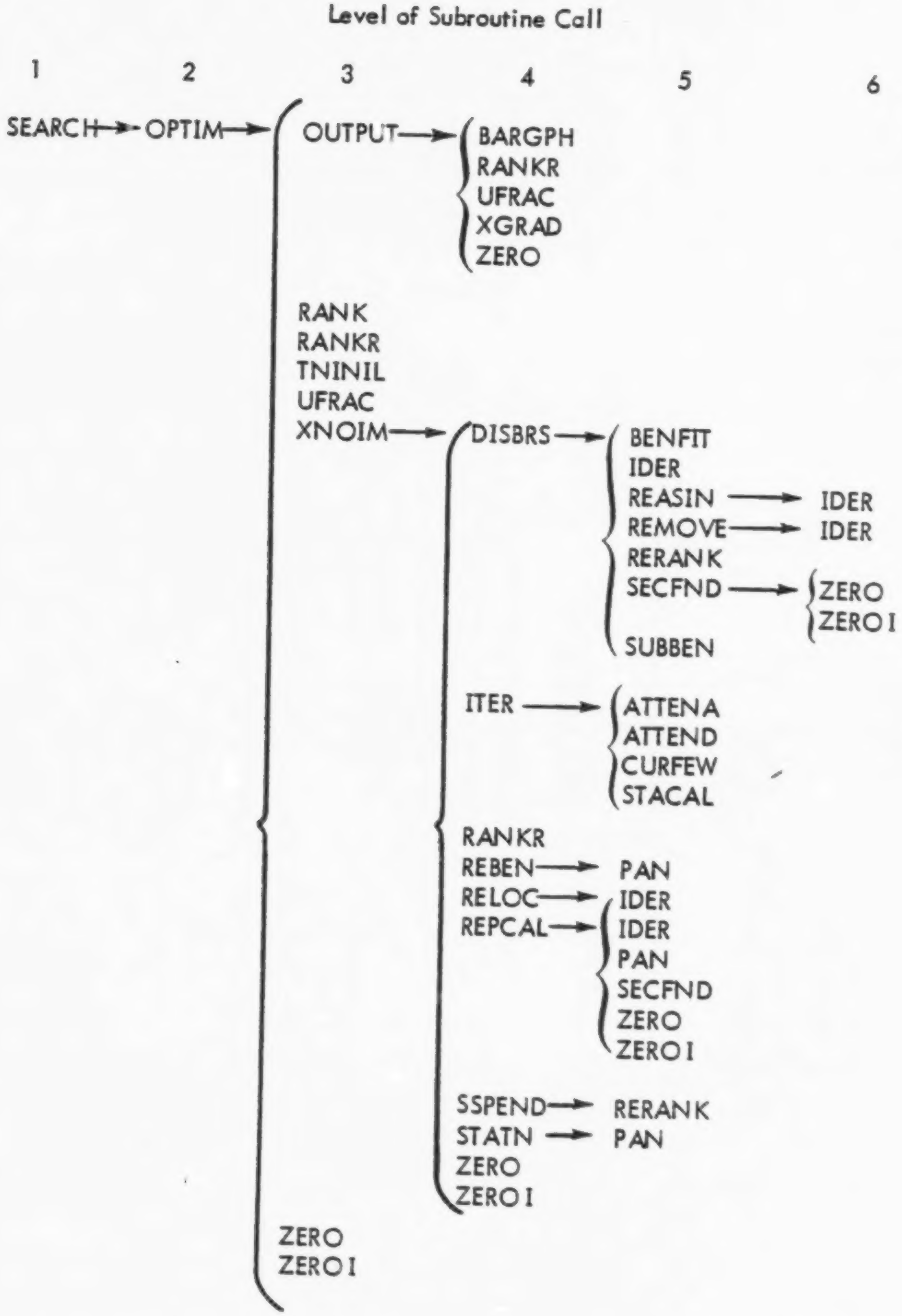

Level of Subroutine Call
1
2
3
4
5
6
SEARCH
OPTIM
OUTPUT
BARGPH
RANKR
UFRAC
XGRAD
ZERO
RANK
RANKR
TNINIL
UFRAC
XNOIM
DISBRS
BENFIT
IDER
REASIN
IDER
REMOVE
IDER
RERANK
SECFND
ZERO
ZEROI
SUBBEN
ITER
ATTENA
ATTEND
CURFEW
STACAL
RANKR
REBEN
PAN
RELOC
IDER
REPCAL
IDER
PAN
SECFND
ZERO
ZEROI
SSPEND
RERANK
STATN
PAN
ZERO
ZEROI
ZERO
ZEROI

Figure A-3. Subroutine Linkages (Alphabetical Order) for the Main Optimization Process, Codeword OPT.

Table A-5

Alternatives Analyzed by Noizop

1. Baseline Case.
2. Two Times Residential Population Density of Baseline Case.
3. Community One-Half the Size of the Baseline Case.
4. Removing the Motorcycle Noise Source and Countermeasure.
5. Removing the Path-Receiver Countermeasure.
6. The Baseline Case without the Noise Source Attitudinal Adjustments.

1. Baseline

This case, reanalyzed for this document with a few modifications, is thoroughly described in the User's Guide, Section 5.2, where the input data is described and the complete computer output is presented. The modifications to the input data reflect the changes made to Noizop to include additional capabilities required for application by local governments. The specific changes to the input data are detailed below.

1. The countermeasure type numbers were redefined to reflect the new designations (see Table A-2). The countermeasures used in the analysis of the alternatives are listed in Table A-6.
2. The two-dimensional enforcement type countermeasures were removed; this concept presents an additional complexity beyond the scope of this manual (see User's Guide, Section 4.2).
3. The countermeasure manipulation indicators were redefined according to the new formula.
4. The linear transfer function specification allowing more than 100 percent impact was removed as this option is now default.

Table A-6

Countermeasures Defined for Noizop Analysis of Alternatives

```
--------- AUTOMOBILES LOW  SPEED NEW VEHICLES SOURCE REDUCTION
COUNTERMEASURE  1 TYPE  6 'EXCL TRT' APPLIES TO: AUTOMOBILES LOW  SPEED LINE SRC
                                                 AUTOMOBILES LOCAL TRAFFIC SOURCE

--------- AUTOMOBILES LOW  SPEED EXISTING VEHICLES RETROFIT SOURCE REDUCTION
COUNTERMEASURE  2 TYPE  6 'EXCL TRT' APPLIES TO: AUTOMOBILES LOW  SPEED LINE SRC
                                                 AUTOMOBILES LOCAL TRAFFIC SOURCE

--------- AUTOMOBILES LOW SPEED OOS ENFORCEMENT
COUNTERMEASURE  3 TYPE  5 'DB  RED ' APPLIES TO: AUTOMOBILES LOW  SPEED LINE SRC
                                                 AUTOMOBILES LOCAL TRAFFIC SOURCE

--------- MOTORCYCLES LOW SPEED OOS ENFORCEMENT
COUNTERMEASURE  4 TYPE  5 'DB  RED ' APPLIES TO: MOTORCYCLES LOW  SPEED LINE SRC.
                                                 MOTORCYCLES LOCAL TRAFFIC SOURCE

--------- TRUCKS      LOW  SPEED NEW VEHICLES SOURCE REDUCTION
COUNTERMEASURE  5 TYPE  4 'PART TRT' APPLIES TO: TRUCKS      LOW  SPEED LINE SRC.

--------- TRUCKS      HIGH SPEED TIRE NOISE REDUCTION
COUNTERMEASURE  6 TYPE  4 'PART TRT' APPLIES TO: TRUCKS      HIGH SPEED LINE SRC.

--------- BUSES       LOW  SPEED SOURCE REDUCTION, NEW AND EXISTING VEHICLES
COUNTERMEASURE  7 TYPE  5 'DB  RED ' APPLIES TO: BUSES       LOW  SPEED LINE SRC.

--------- AIRCRAFT    SOUND ABSORPTION MATERIAL NACELLE TREATMENT SOURCE REDUCTION
COUNTERMEASURE  8 TYPE  4 'PART TRT' APPLIES TO: AIRCRAFT    COMMERCIAL, FLIGHT

--------- AIRCRAFT    FLIGHT PATH REROUTING (EFFECTIVELY A FLIGHT FREQUENCY RED.)
COUNTERMEASURE  9 TYPE  1 'RED FREQ' APPLIES TO: AIRCRAFT    COMMERCIAL, FLIGHT

--------- AIRCRAFT    REDUCTION OF NIGHT OPERATIONS
COUNTERMEASURE 10 TYPE  2 'NITE RED' APPLIES TO: AIRCRAFT    COMMERCIAL, FLIGHT

--------- RAILROAD    LOCOMOTIVE MUFFLERS, SOURCE REDUCTION
COUNTERMEASURE 11 TYPE  4 'PART TRT' APPLIES TO: RAILROAD    LOCOMOTIVES, LINE S.

--------- PATH-RECEIVER CONTROL: INSULATION, BARRIERS, LAND ACQ. AND PEOPLE RELOC.
COUNTERMEASURE 12 TYPE  8 'P-R MOD ' APPLIES TO: ALL SOURCES
```

5. The specification of upper and lower criterion levels was removed as this information is now default.

6. Attitudinal adjustments with the following parameters were made to low speed arterial and local traffic (collector streets), motorcycle and locomotive and car railroad noise sources (numbers 6, 7, and 9, 10, respectively).

Source	Adjustment, dB
Motorcycles	-6. (Increase)
Railroad	5. (Decrease)

These hypothetical adjustments compensate for the fact that the annoyance reaction to motorcycle noise is indicative of a noise level 6 dB higher than for other sources. The railroad correction illustrates that a noise level of 5 dB greater than for the other sources is required to produce a comparable annoyance reaction.

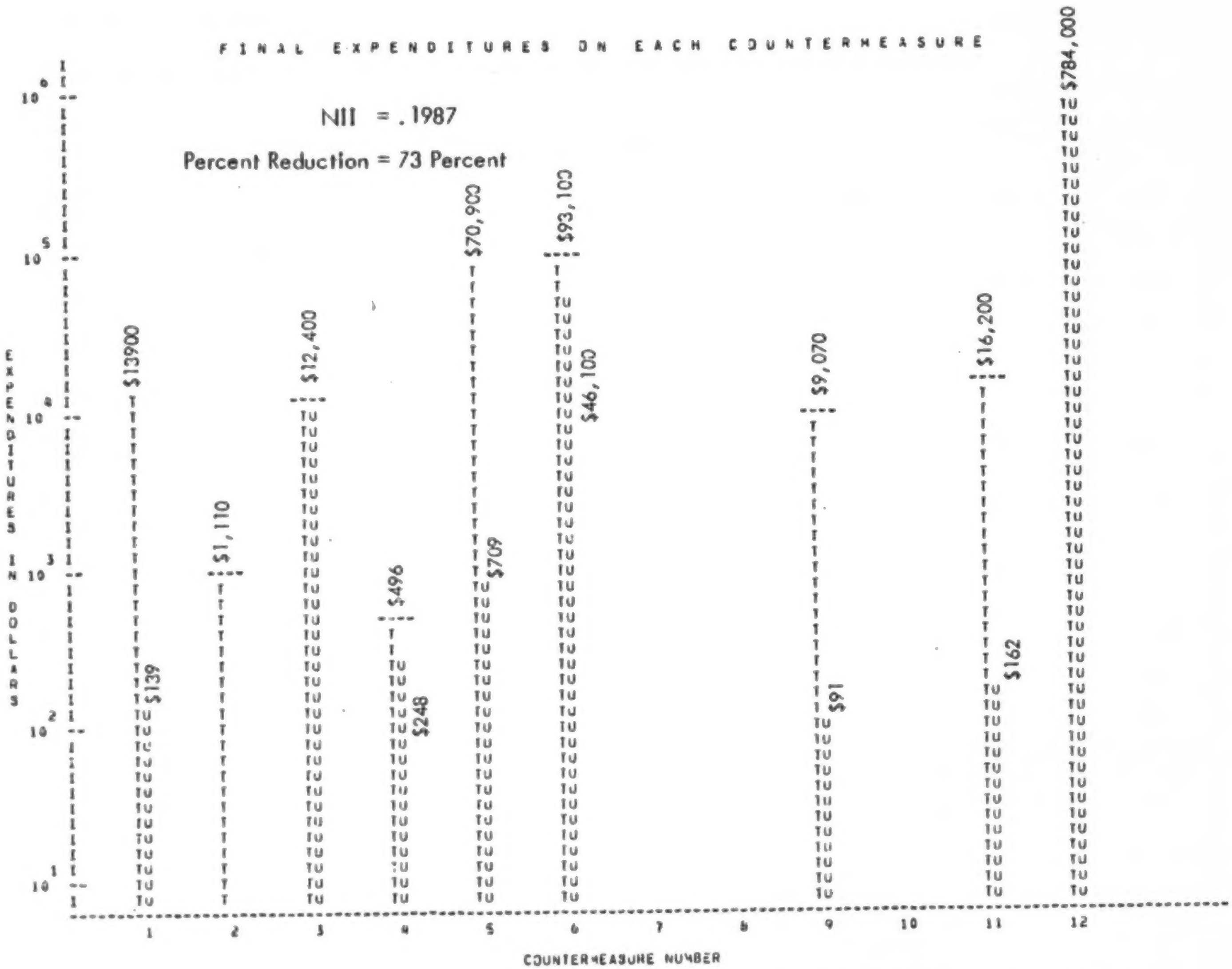
7. Hypothetical user cost fractions were entered as shown below for countermeasures 1 through 12, respectively.

Countermeasure Number	1	2	3	4	5	6	7	8	9	10	11	12
User Cost Fraction	.01	0.	1.	0.5	.01	0.5	.01	.01	.01	.01	.01	1.

8. The total budget was specified as $1 million and the gradient stepsize and initial maximum expenditure ratio were allowed to default to $10 thousand and 10., respectively. No marginal search (expenditure retraction stages) was initiated.

The results of the optimization procedure are shown in Figure A-4. The path-receiver countermeasure absorbed nearly 80 percent of the total budget. The total user cost is therefore high because the local government, in this hypothetical example, is assumed to be responsible for the entire cost of path-receiver countermeasures (countermeasure number 12 above). Other significant aspects of the optimized baseline expenditures are:

- Maximum amounts were spent on countermeasures for existing automobile retrofit source reduction and enforcement thereof. An equal amount was spent on new vehicle source reduction, but this did not represent the maximum allowed expenditure. The motorcycle countermeasure, an enforcement action to eliminate the very noisy offenders, received the maximum allotment.
- A large amount was spent on both truck noise countermeasures with the high speed tire noise source receiving the maximum allowed expenditure.
- The bus noise countermeasure did not receive any funding but was the highest ranking countermeasure at the end of the optimization process. Therefore, if additional funds were available, the bus noise countermeasure would be the next to receive funding, assuming, of course, that the additional funds would either be insufficient for an additional discrete path-receiver expenditure or that next path-receiver measure would be less effective than the bus noise countermeasure.
- The only aircraft countermeasure selected was flight path routing. The rerouting of all the aircraft accounts for the subsequent ineffectiveness of both the Sound Absorbing Material (SAM) and night curfew countermeasures.



NII = .1987

Percent Reduction = 73 Percent

Figure A-4. Baseline Case Optimization Results. T = Total Cost = $1,000,000; U = User Cost = $844,000.

Table A-7

Extent of Countermeasure Application to the Six Hypothetical Examples. The Countermeasure Application Corresponds to Total Expenditures on Each Countermeasure as Seen in Figures A-4 through A-7, A-10 and A-11

Countermeasure	Case					
	1 Baseline	2 Twice Residential Population Density	3 Community One-Half Site	4 Removing Motorcycle Source and Countermeasure	5 No Path-Receiver Countermeasure, Smaller Budget	6 No Attitudinal Adjustments
1. Percent of Automobiles Receiving 3.5 dB Reduction*	16%	19%	1%	13%	0	20%
2. Percent of Automobiles Receiving 3.5 dB Reduction*	57%	57%	57%	57%	57%	57%
3. Decibel Reduction in Automobile L_{eq} due to Enforcement of Ordinance	6.2 dB	6.2 dB	6.2 dB	6.2 dB	5.9 dB	6.2 dB
4. Decibel Reduction in Motorcycle L_{eq} due to Enforcement of Ordinance	17 dB	17 dB	17 dB	___**	17 dB	17 dB
5. Percent of Trucks Receiving 12 dB Engine Noise Reduction	36%	36%	36%	36%	25%	36%
6. Percent of Trucks Receiving 5 dB Tire Noise Reduction	100%	100%	100%	100%	33%	100%
7. Decibel Reduction In Bus L_{eq}	0	0	0	5.1 dB	0	0
8. Percent of Aircraft Receiving SAM Treatment	0	0	0	0	0	0
9. Percent of Aircraft Rerouted	100%	100%	100%	100%	100%	100%
10. Percent of Aircraft Night Operations Eliminated	0	0	0	0	0	0
11. Percent of Railroad Locomotives Receiving 6 dB Muffler Treatment	100%	100%	100%	100%	100%	100%
12. Total Dollar Expenditure on Barriers and Soundproofing	$784,000	$775,000	$791,000	$775,000	___**	$773,000

*Countermeasures 1 and 2 are mutually exclusive (Countermeasure Type 6). Countermeasure 1 applies to new vehicles, Countermeasure 2 applies to existing vehicles.

**Countermeasure not defined.

- The railroad countermeasure applying to the locomotive source also received maximum funding which is consistent with the high source ranking of the locomotive noise source (see Figure A-8).

2. Two-Times Residential Population Density of Baseline Case

The data set for this case is identical to the data set for case number 1 with the exception that every cell in a residential land use area has double the baseline population.

The results of this case, shown in Figure A-5 show almost the same results as for case number 1., the difference being that the low speed automobile source received slightly more treatment at the expense of a path-receiver countermeasure.

3. Community One-Half the Size of the Baseline Case

For this alternative, every other cell defined for the baseline case was removed to simulate a smaller community. As can be seen in Figure A-6, the results are quite similar to the baseline case. The detailed disposition of the individual path-receiver measures (i.e., barriers and soundproofing) was, of course, quite different since the configuration of the community and, hence, the relative cost-effectiveness of all the possible individual path-receiver measures is different.

4. Removing the Motorcycle Noise Source and Countermeasure

Removing the motorcycle source has the effect of slightly altering the community so that an expenditure on the bus countermeasure becomes effective. No other significant differences from the baseline case are present. Figure A-7 illustrates the results. Note that the motorcycle countermeasure (number 4) was removed for this case meaning that in Figure A-7, countermeasures numbered 4 through 11 correspond to countermeasures numbered 5 through 12 in the five other cases.

An interesting result of removing the motorcycle source is a change in the population-weighted noise source impact ranking in the community. Figure A-8 is the source ranking for the baseline case, including the motorcycle source. Figure A-9 is the source ranking with the motorcycle source removed.

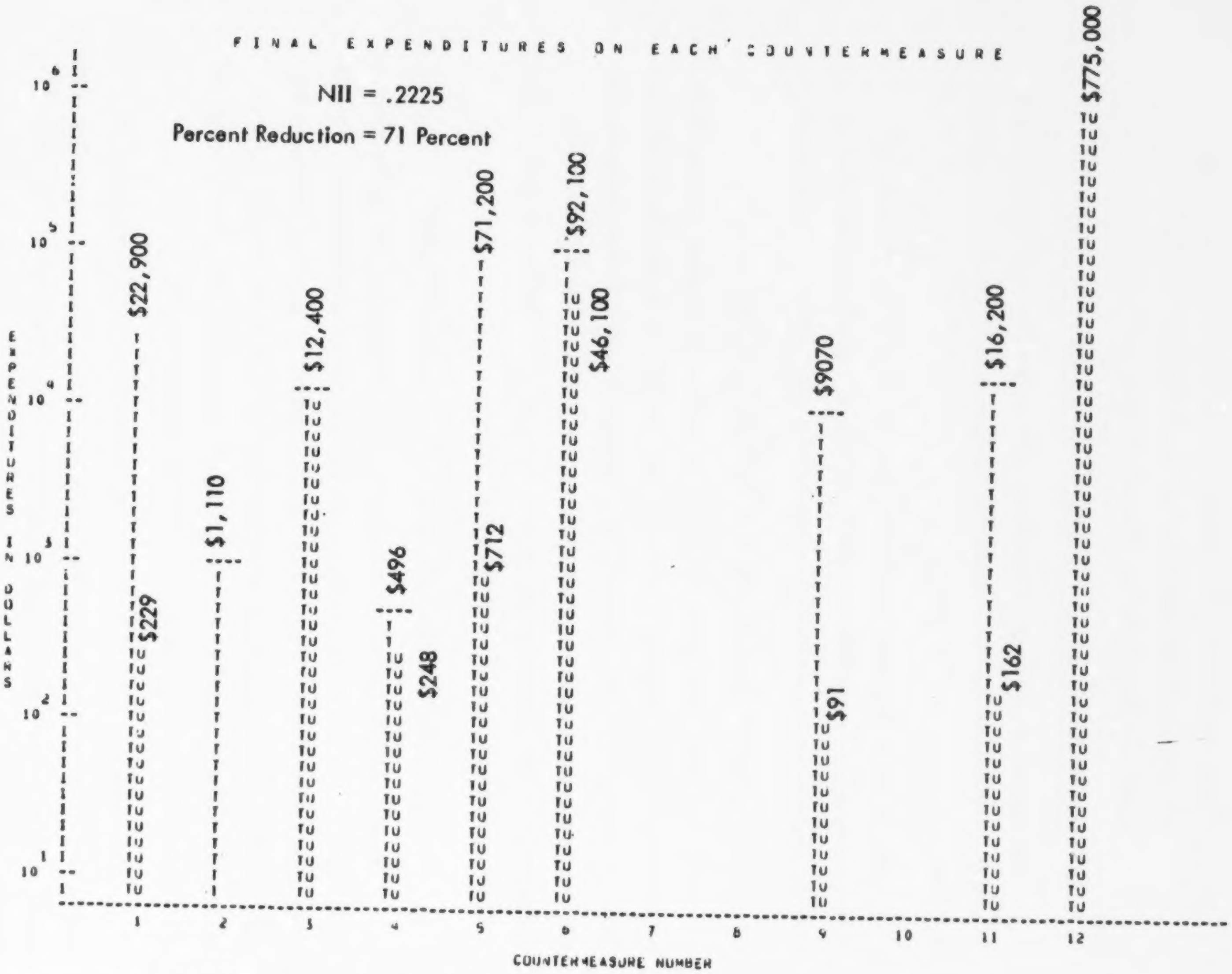


Figure A-5. Final Expenditures for Case Number 2, Two Times Residential Population Density of Baseline Case
Total Cost = $1,000,000; User Cost = $834,000

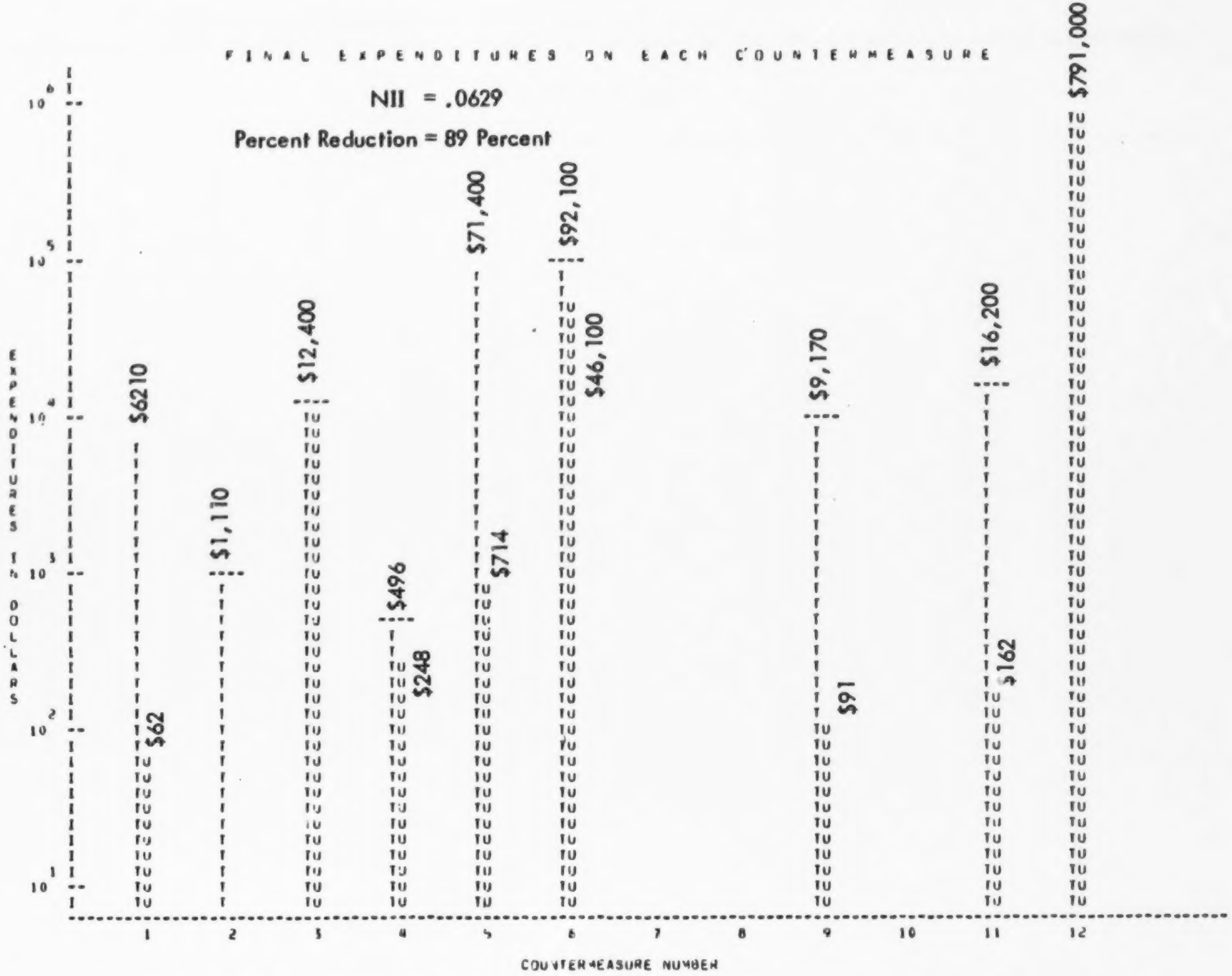


Figure A-6. Final Expenditures for Case Number 3, Community One-Half the Size of the Baseline Case
Total Cost = $1,000,000; User Cost = $851,000

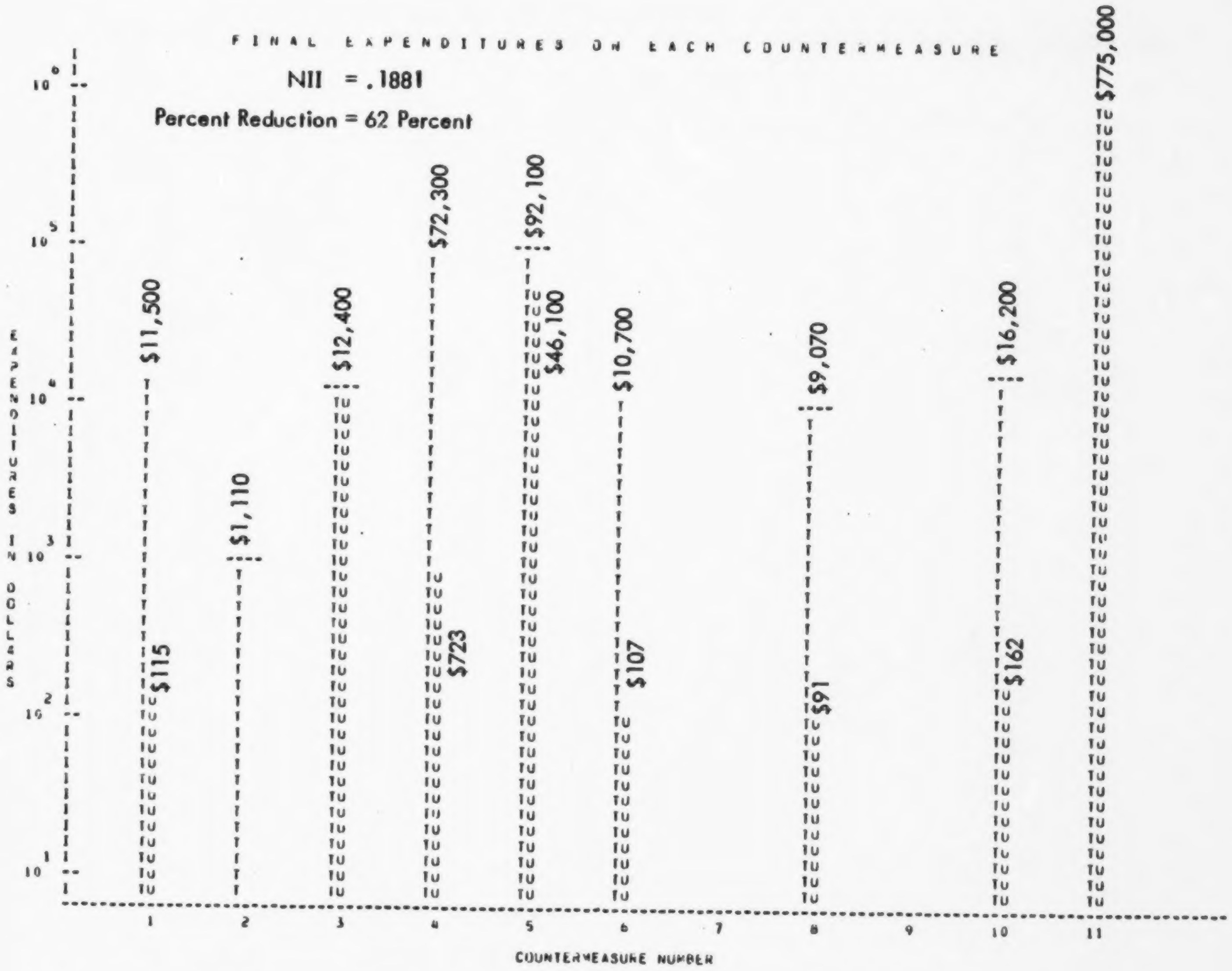


Figure A-7. Final Expenditures for Case Number 4, Removing the Motorcycle Noise Source and Countermeasures
Total Cost = $1,000,000; User Cost = $834,000

```
MOST OFFENDING SOURCES:                                SOURCE NO.

                 1   MOTORCYCLES LOW  SPEED LINE SRC.      ( 6)
                 2   MOTORCYCLES LOCAL TRAFFIC SOURCE      ( 7)
                 3   RAILROAD    LOCOMOTIVES, LINE S.      ( 9)
                 4   AUTOMOBILES LOW  SPEED LINE SRC       ( 1)
                 5   TRUCKS      LOW  SPEED LINE SRC.      ( 4)
                 6   TRUCKS      HIGH SPEED LINE SRC.      ( 5)
                 7   AUTOMOBILES HIGH SPEED LINE SRC       ( 2)
                 8   AUTOMOBILES LOCAL TRAFFIC SOURCE      ( 3)
                 9   RAILROAD    CARS, LINE SOURCE         (10)
                10   AIRCRAFT    COMMERCIAL, FLIGHT        (11)
                11   BUSES       LOW  SPEED LINE SRC.      ( 8)
```

Figure A-8. Noise Source Ranking of Baseline Case

```
MOST OFFENDING SOURCES:                                SOURCE NO.

                 1   AUTOMOBILES LOW  SPEED LINE SRC       ( 1)
                 2   TRUCKS      LOW  SPEED LINE SRC.      ( 4)
                 3   TRUCKS      HIGH SPEED LINE SRC.      ( 5)
                 4   RAILROAD    LOCOMOTIVES, LINE S.      ( 9)
                 5   AUTOMOBILES HIGH SPEED LINE SRC       ( 2)
                 6   AUTOMOBILES LOCAL TRAFFIC SOURCE      ( 3)
                 7   RAILROAD    CARS, LINE SOURCE         (10)
                 8   AIRCRAFT    COMMERCIAL, FLIGHT        (11)
                 9   BUSES       LOW  SPEED LINE SRC.      ( 8)
```

Figure A-9. Noise Source Ranking with Motorcycle Source Removed

Prior to the removal of the dominant motorcycle sources, the railroad locomotive noise source had a greater impact than the low speed automobile source and both the low and high speed truck noise sources. The counterintuitive result of removing the motorcycle source is that the automobile and truck noise source now have greater impact relative to the railroad locomotive source than they did before.

An apparent explanation is that the presence of the annoying motorcycle source had the effect of masking the automobile and truck sources. In other words, with the motorcycles no longer there, the automobiles and trucks become the dominant sources in areas where traffic is dominant, but the number of areas impacted by railroad noise remains unchanged.

5. No Path-Receiver Countermeasure

Since the path-receiver countermeasures received the preponderance of the expenditure allocation in the other cases, the removal of this countermeasure provides potentially the most interesting variant to the baseline case. For this case, the total budget was reduced to $100 thousand since a $1 million budget would allow maximum application of all the countermeasures and no interesting results would be obtained. Figure A-10 illustrates these results.

Countermeasure number 1, new automobile source reduction, now receives no expenditures while the remainder is disbursed to counteremasures 3, 5, and 6 (see Table A-6). Overall, the disposition of these countermeasures is similar to the baseline case. What this case illustrates is that, for this community, the optimum expenditures among the remaining countermeasures is only slightly altered when the most cost-effective countermeasure (Barriers and Soundproofing) is removed.

6. No Attitudinal Adjustments

Removing the attitudinal adjustments had little effect since the motorcycles and railroad noise source predominate even without the attitudinal corrections. The effect of the attitudinal corrections was to increase the apparent motorcycle levels by

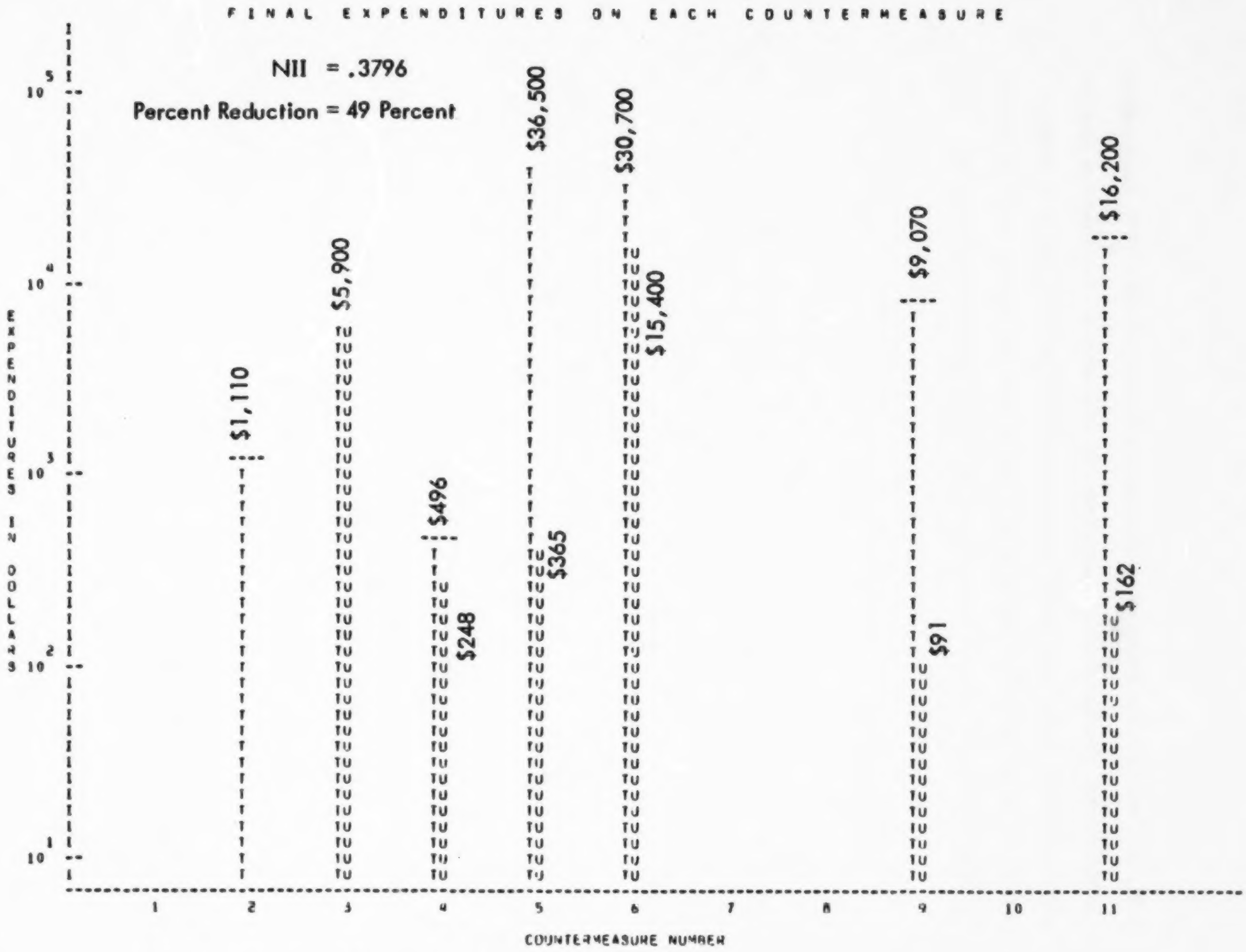


Figure A-10. Final Expenditures for Case Number 5, No Path-Receiver Countermeasure
Total Cost = $100,000; User Cost = $22,100

6 dB, and decrease the apparent railroad source levels by 5 dB. With these adjustments removed, the motorcycle countermeasure still remains very effective and the effectiveness of the railroad countermeasure is not altered sufficiently to make a noticeable difference. Countermeasures 1 and 5 received slightly more funding at the expense of path-receiver measures. Figure A-11 summarizes the results.

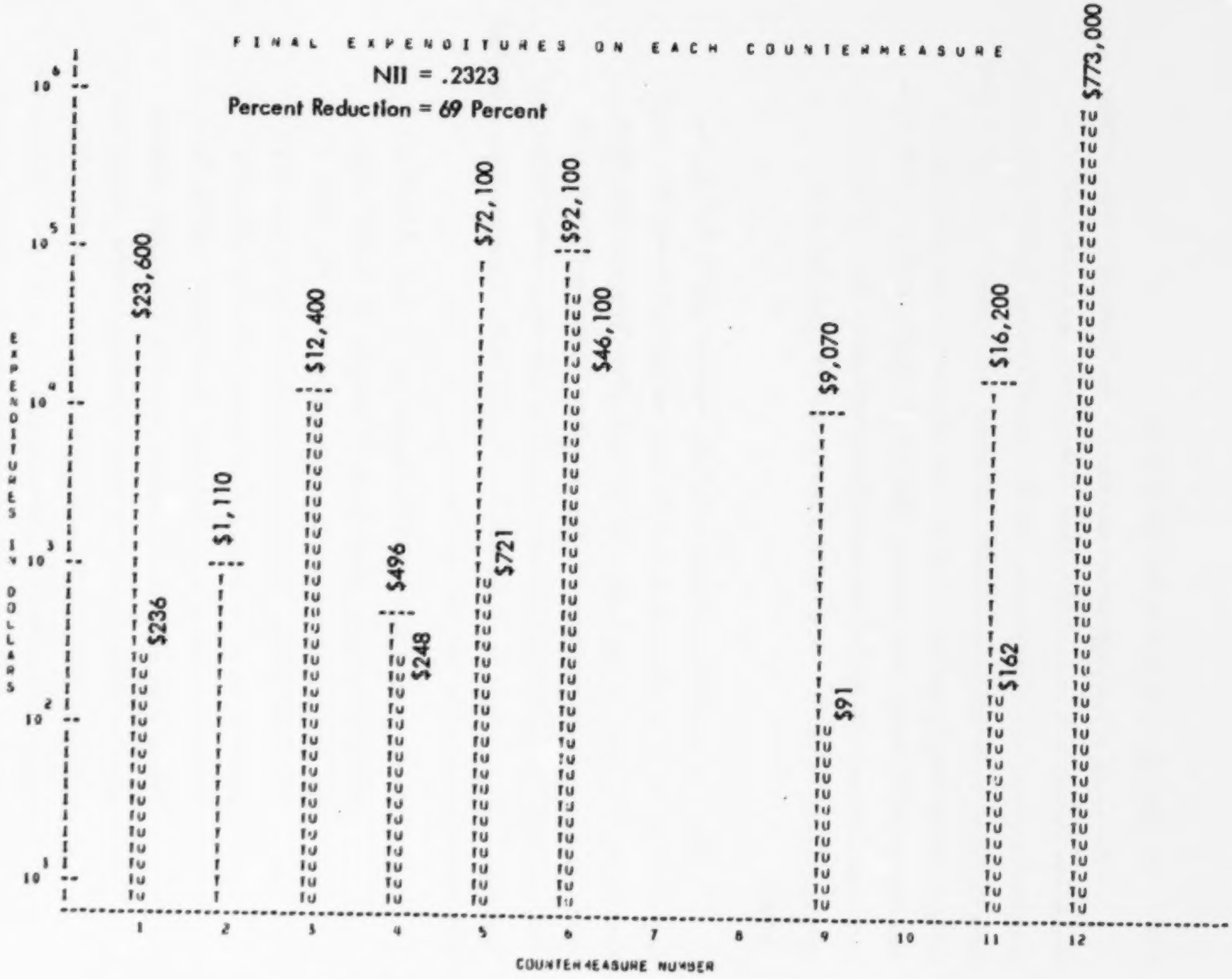


Figure A-11. Final Expenditures for Case Number 6, No Attitudinal Adjustments
Total Cost = $1,000,000; User Cost = $833,000

A.4 Summary of the Allentown Strategy Analysis

The results of applying methods developed in the Community Noise Strategy Guidelines Manual to the city of Allentown, Pennsylvania, are summarized in this section of Appendix A. In conjunction with EPA and Allentown, problem noise sources were identified on the basis of acoustical, attitudinal, and complaint information, and a list of countermeasures was derived which were felt to be the most promising and practical means of abating these sources. The costs incurred by society and the noise reductions achieved with each of the selected countermeasures were estimated from data supplied by Allentown, using methods described in the main text of this manual.

The noise optimization program, Noizop, was then used to find optimal degrees of societal expenditure on each of the selected countermeasures for various overall spending limits. In particular, optimal expenditure strategies were found which would provide the maximum reduction in impacts from noise (1) in the year 1980 and (2) in the year 1988, for a nominal expected city noise control budget, as suggested by the Allentown Quiet Communities Program Staff. These results are presented and discussed below. The main findings are:

- The most cost-effective countermeasures are (1) those which abate emergency vehicles, since the cost of abating this source is very low, and (2) those which abate automobiles, since this source is both the most pervasive in Allentown (as was indicated by the acoustical survey) and also one of the most annoying (according to the attitudinal survey). Although it is not known whether the main problem of automobile noise is caused by a few noise-modified vehicles (which are the main target of automobile noise countermeasures in this analysis) or by the more numerous but quieter majority, it is suggested that additional countermeasures not considered in this analysis which can help reduce noise impacts from this source should be investigated in the future.

- Very little difference is observed between expenditures optimized in 1980 vs. expenditures optimized in 1988, since most countermeasures are expected to take effect immediately (1978) and remain unchanged thereafter.
- A budget which is approximately 1/3 lower than the present budget anticipated by the city of Allentown may be more desirable, as measured in terms of the cost per unit measure of achievable reduction in noise impact.

Inputs

The countermeasures analyzed in the optimization program are described below.

1. Property Standard applied to Noise from Garden Equipment and People. This property standard would set noise emission limits at the property line of between 75 and 80 dB for one hour due to noise from garden equipment or activity by people (i.e., playing loud music, etc.)
2. Noise Ordinance Applied to Motorcycles. A noise ordinance was considered which would consist of four parts:
   (1) Enforcing the federal new vehicle standard on motorcycles (83 dB in 1978, 80 dB in 1980)*
   (2) Enforcing the Pennsylvania Department of Transportation (Penn DOT) low speed operational regulations on motorcycles (84 dB)
   (3) Enforcing operational controls (reducing excess accelerations)
   (4) Enforcing an equipment standard (e.g., "all motorcycles shall have proper mufflers")
3. Noise Ordinance Applied to Autos. A noise ordinance applied to autos was considered which would consist of three parts:

---

*All regulation limits given are maximum low speed passby levels measured at 15 m.

(1) Enforcing the Penn DOT low speed operational regulations on autos (84 dB)

(2) Enforcing operational controls (reducing excess accelerations)

(3) Enforcing an equipment standard (e.g., "all autos shall have proper mufflers")

4. Noise Ordinance Applied to Trucks.

A noise ordinance applied to trucks was considered which would consist of four parts:

(1) Enforcing the federal new vehicle standard on trucks (83 dB in 1978, 80 dB in 1980)

(2) Enforcing the Penn DOT low speed operational regulations on trucks (88 dB)

(3) Enforcing operational controls (reducing excess accelerations)

(4) Enforcing an equipment standard (e.g., "all trucks shall have proper mufflers")

5. Noise Ordinance Applied to Buses.

A noise ordinance applied to buses was considered which would consist of four parts:

(1) Enforcing the proposed federal new vehicle standard on buses (83 dB in 1979, 80 dB in 1983, and 77 dB in 1985)

(2) Enforcing the Penn DOT low speed operational regulations on buses (88 dB)

(3) Enforcing operational controls (reducing excess idling near residences)

(4) Enforcing an equipment standard (e.g., "all buses shall have proper mufflers")

6. Operational Controls Applied to Emergency Vehicles.
This countermeasure would reduce the amount of time sirens are used by restricting their use to emergency situations.

7. New Vehicle Standard Applied to Garbage Trucks.
This noise standard would enforce federal noise regulations on newly manufactured garbage trucks (78 dB in 1979, 75 dB in 1982)

8. Mode Transfer from Autos to Buses.
This countermeasure would use education and advertisement media to get more commuters to use buses instead of autos.

9-13. Education and Complaint Mechanism Applied to (9) Autos and Motorcycles, (10) Trucks and Buses, (11) Garbage Trucks and Emergency Vehicles, (12) Garden Equipment and People, and (13) Pets

These countermeasures have to do with informing the public about the causes and effects of community noise and establishing a mechanism such as a noise "hot line" which the public can use to complain about noisy sources such as motorcycles, private parties, or industrial plants.

14. Stationary Source Controls Applied to Fairgrounds.
This countermeasure would reduce noise emissions from equipment and loud music typically found at fairs.

15. Stationary Source Controls Applied to Music Clubs.
This countermeasure would reduce the undesirable source of music clubs propagating into nearby residential areas by requiring owners to provide sound insulation treatment of the exterior walls of their clubs.

16. Building Insulation and Codes.
Twenty areas ("cells") throughout the city were selected as potential candidates for building insulation treatment. The noise optimization program was then allowed to pick the cells which needed insulation.

In addition to inputs which defined the above potential countermeasures, an annual noise control budget of $123,000 for the city government of Allentown was selected. This number is based on the man-year estimates provided by the city shown in Table A-8.

Table A-8
Manpower Distribution Estimated by Allentown for
Various Noise Control Activities, Man-years

	Government Entity Performing Activity			
Noise Control Activity	QCP	Police	Information Services	Community Planners
Stationary Source Control	1/2	-	-	-
Motor Vehicle Noise Enforcement	1	2	-	-
Education and Complaint Activities	1	-	1/2	1/2
Bus Ridership Campaign	1/2	-	-	-
Building Insulation Program	1	-	-	-

Total = 7 man-years

The total costs defined for each countermeasure include all costs incurred by society. To find the costs incurred by Allentown's city government alone, a "City Fraction" was estimated for each countermeasure. These city fractions are shown in Table A-9. Note that some of the countermeasures are expected to be paid for almost entirely by Allentown (such as the Bus Noise Ordinance), while others only involve relatively minor government expense (such as a building insulation program).

Outputs

The optimum total (T) and city government (U) expenditures selected by Noizop for each countermeasure at the city budget level defined above are shown

Table A-9

Effectiveness of Countermeasures in the Allentown Strategy Analysis

No.	Countermeasure	Noise Source Affected	City(2) Fraction	Cost/Effectiveness (Percent of Maximum Allowable Expenditure)		Comments
				1980	1988	
1	Property Standard	Garden Equipment, People	0.995	0%	0%	Not very cost/effective
2	Noise Ordinance (1)	Motorcycles	0.25	51	51	Less should be spent on this countermeasure as budget increases
3	Noise Ordinance (1)	Autos	0.84	100	100	Very cost/effective
4	Noise Ordinance (1)	Trucks	0.11	100	49	Cost/Effective - in 1980, additional money should be spent here next
5	Noise Ordinance (1)	Buses	1.00	0	100	Only cost/effective in the long term
6	Operational Control	Emergency Vehicles	1.00	100	100	Very cost/effective
7	New Vehicle Standard	Garbage Trucks	0.09	0	100	Only cost/effective in the long term
8	Mode Transfer	Autos, Buses	1.00	100	100	Very cost/effective
9	Education and Complaint Mechanism	Autos, Motorcycles	1.00	100	100	Very cost/effective
10	Education and Complaint Mechanism	Trucks, Buses	1.00	0	0	Not cost/effective
11	Education and Complaint Mechanism	Garbage Trucks, Emergency Vehicles	1.00	100	100	Very cost/effective
12	Education and Complaint Mechanism	Garden Equipment, People	1.00	85	86	Quite cost/effective
13	Education and Complaint Mechanism	Pets	0.48	100	100	Very cost/effective
14	Stationary Source Controls	Fairgrounds	0.54	0	0	Not cost/effective
15	Stationary Source Controls	Music Clubs	0.37	0	0	Not cost/effective
16	Building Insulation and Codes	All Sources	0.04	5	5	Only cost/effective at high levels of expenditures

(1) Includes: New Vehicle Standard (except for Autos), Operational Standard, Operational Controls, and Equipment Standard

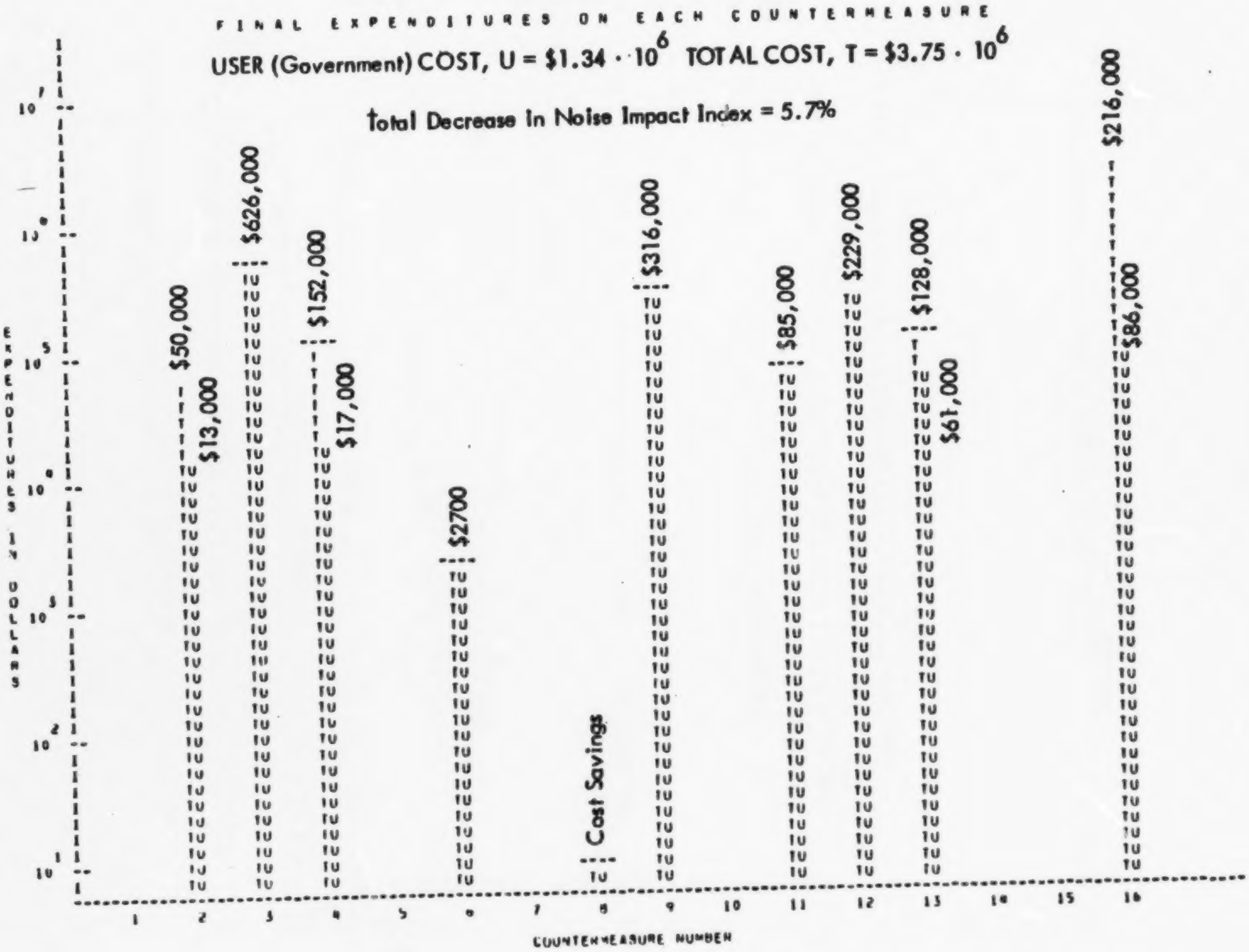
(2) Fraction of countermeasure costs incurred by the City of Allentown.

in Figures A-12 and A-13 for the years 1980 and 1988, respectively. Note that the costs shown in these figures are "total discounted dollars," with an assumed discount rate of 10 percent. These costs indicate the total amount of money which is needed for each countermeasure, from now until infinity. To find the equivalent annual cost, divide these costs by 11. For example, when the optimization is made in 1980 (Figure A-12), the optimal annual expenditure on Countermeasure No. 2 is 50,000 ÷ 11 = $4550. A discussion of present value analysis and discounted costs is provided in Section 3.4 of the main text of this manual.

Pursuing other aspects, two additional Noizop runs were made. Figure A-14 shows the optimum expenditure strategy in 1980 if no building insulation program is allowed. The same input data and budget are used here as were used in Figure A-12. Finally, Figure A-15 shows the expenditure pattern at a somewhat reduced budget (an annual city budget of $82,000 instead of $123,000). This budget seems to be a more desirable one for the countermeasures under consideration, since the rate of reduction in noise impact achieved per dollar expended reduces rapidly for higher budgets.

Discussion of Results

The cost/effectiveness of each countermeasure was shown in Table A-8 in terms of the percent of maximum allowable expenditure which Noizop chose to spend. A maximum allowable expenditure was defined for each countermeasure and supplied as input information, based on practical, technical, and economic grounds. The implications of these cost/effective percentages is discussed in the following for each countermeasure.



FINAL EXPENDITURES ON EACH COUNTERMEASURE

USER (Government) COST, $U = \$1.34 \cdot 10^6$ TOTAL COST, $T = \$3.75 \cdot 10^6$

Total Decrease in Noise Impact Index = 5.7%

Figure A-12. Expenditures Optimized in 1980

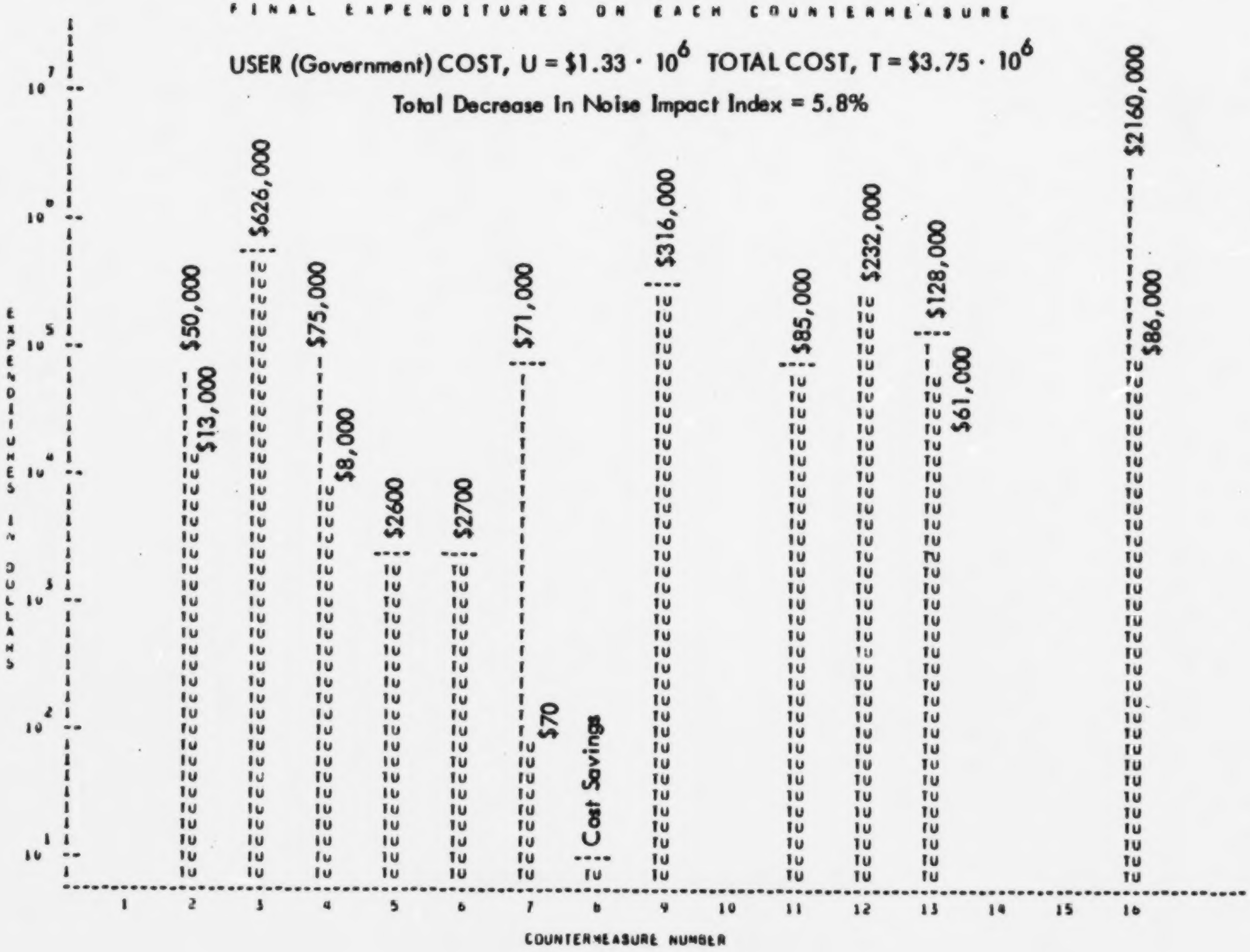


Figure A-13. Expenditures Optimized In 1988

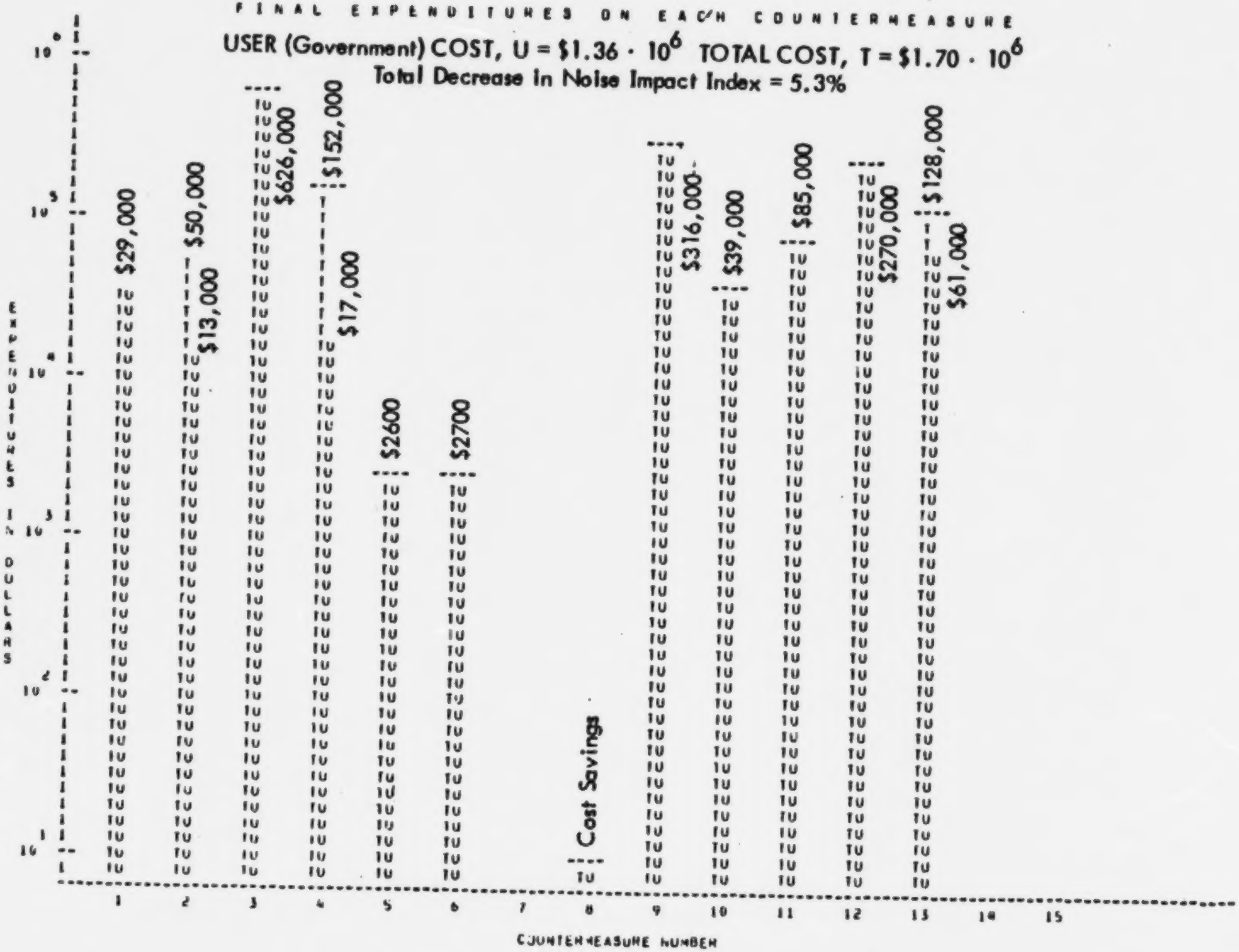


Figure A-14. No Building Insulation, Optimized in 1980

FINAL EXPENDITURES ON EACH COUNTERMEASURE

USER (Government) COST, $U = \$0.91 \cdot 10^6$ TOTAL COST, $T = \$1.10 \cdot 10^6$

Total Decrease in Noise Impact Index = 5.1%

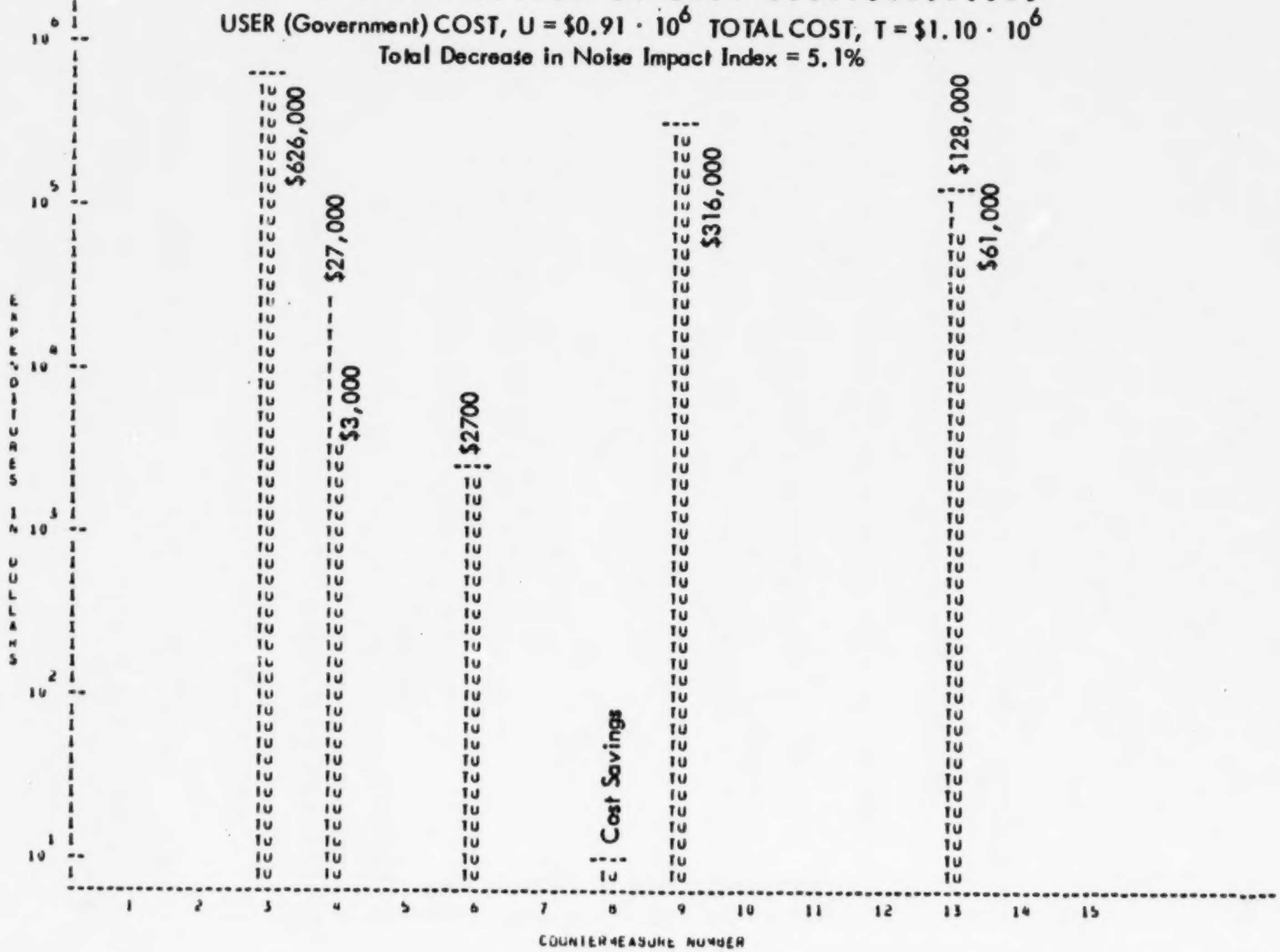


Figure A-15. Lower Budget, Optimized in 1980

1. Property Standard applied to Garden Equipment and People

   - Noizop did not choose this countermeasure in either 1980 or 1988. This is probably due to the fact that noise levels from garden equipment and people were fairly low compared to other noise sources, due to their intermittent and transitory nature. When the building insulation countermeasure is eliminated from consideration, some money is spent on this measure (Figure A-14), but only a relatively small amount ($2640 per year).
   - Implication - A property line standard against garden equipment and people noise is not cost effective.

2. Noise Ordinance applied to Motorcycle

   - This countermeasure is relatively cost/effective at low expenditure levels, but decreases in comparison with other measures as expenditures increase.
   - Implications - A motorcycle noise ordinance is warranted and will be effective even if relatively mild restrictions are enforced. This is because a small percent of the motorcycles produce noise levels which are much higher than the average motorcycle levels. As a result, even a simple equipment standard requiring "proper mufflers" should have immediate benefit, as long as it is adequately enforced.

3. Noise Ordinance applied to Autos

   - The maximum allowable expenditure was reached, indicating that automobile noise reduction should be a primary target for the city of Allentown. The maximum expenditure corresponds to an operational regulation level of 74 dB, which is 10 dB lower (more strict) than the present Pennsylvania DOT noise regulation.

3. Noise Ordinance applied to Autos (Continued)

- Implications – Allentown may wish to establish standards for automobiles more strict than existing state standards. These standards should probably be directed first at autos which have modified, improper, or inadequate exhaust systems. A fairly strict equipment standard which specifies allowable exhaust modifications and minimum insertion loss values for replacement parts may be very effective in this regard. To abate the impacts of the general automobile population, alternate strategies must be used, some of which lie outside the municipal government's domain. These countermeasures might include traffic controls on minor residential streets, rerouting certain major boulevards to less populous areas, and barriers located in strategic positions.

4. Noise Ordinance applied to Trucks

- Maximum expenditure limits were reached in the 1980 run, but other countermeasures were found to be somewhat more cost effective in 1988.
- Implications– A truck noise ordinance, parallelling Federal and State standards, is worthwhile at the present time, but may be deemphasized in the future.

5. Noise Ordinance applied to Buses

- While no expenditures were made for the 1980 case, the maximum expenditure limit was reached in 1988 since more quiet new buses are expected to be operating in the fleet by that time.
- Implications – Allentown should consider enforcing Federal bus noise regulations that may develop in the future. (Note: Federal bus noise regulations are still in the proposal stage).

6. Operational Controls applied to Emergency Vehicles

- This countermeasure received maximum allotment in both analysis years, corresponding to a reduction of 20 percent of the time sirens normally are operating.
- Implications - An emergency vehicle operational control should be implemented which would reduce unnecessary siren use as much as possible.

7. New Vehicle Standard applied to Garbage Trucks

- Similar to Countermeasure No. 5 above.
- Implications - Same as No. 5 above.

8. Mode Transfer from Autos to Buses

- It was found that the cost to society is less if commuters use buses rather than autos, therefore this countermeasure has a "negative cost".
- Implications- Commuters should be urged to ride buses through educational campaigns and increased bus service. A doubling of the bus fleet still saves society money, according to this limited analysis.

9,11,13. Education and Complaint Mechanism applied to (9) Autos and Motorcycles, (11) Garbage Trucks and Emergency Vehicles, and (13) Pets.

- The results for each of these countermeasures was the same, namely, the maximum allowable expenditure was reached.
- Implications - Education and complaint programs should be geared to the above 5 sources of noise. Increased manpower assignments may be warranted in this area, compared with the nominal values suggested by Table A-9 above. As with Countermeasures Nos. 2 and 3 above, for automobiles and motorcycles, the most effective results can be achieved

if attention is paid primarily to those vehicles which have modified or inadequate exhaust systems.

10. Education and Complaint Mechanism applied to Trucks and Buses

- No expenditures were made on this countermeasure. This is probably due to the fact that in Allentown, the major truck routes are well defined, therefore trucks and buses do not affect people as much near their homes, where people are more likely to complain, as they do when people are in transit. Similarly, educational programs directed at bus and truck operators are expected to change their operational habits to a lesser degree, and therefore will reduce noise levels to a lesser degree, than programs directed to more alterable causes of noise such as accelerating or modified autos and motorcycles, unnecessary sirens, or barking dogs.

- Implications - Little effort should be expended on this countermeasure other than to support, in a general way, existing State and Federal truck and bus noise regulations.

12. Education and Complaint Mechanism applied to Garden Equipment and People

- Changes resulting from this countermeasure typically cost less money than changes caused by Countermeasure No. 1, which deals with the same noise sources but may require equipment substitution to meet the regulation. In contrast, education and complaints act to achieve nearly the same ends without large expenditures.

- Implications - To reduce noise from garden equipment and people in the most cost effective way (1) people should be educated as to the effect of their (and their equipment's) noise on others, and (2) a means of complaining about annoying neighborhood noises should be established.

To assist officials in enforcing the reduction of these "annoying noises", as a practical matter, a property standard such as Countermeasure No. 1 may be needed, but the latter should not be implemented in isolation.

14,15. Stationary Source Controls applied to Fairgrounds and Music Clubs

- No expenditures were made on these countermeasures due to their transitory and isolated nature. That is, in comparison with more continuous noise sources such as autos, their average sound levels (L_{eq}) were low. (Note, however, that noise levels for these two sources of noise were estimated without the aid of noise measurements from the acoustical survey.)
- Implications - No substantial noise control activity seems warranted for these two noise sources.

16. Building Insulation and Building Codes

- Only a small portion (5 percent) of the total possible expenditure on this countermeasure was made, since only 5 of 20 possible cells received insulation and the cells which were picked have small floor areas. However, the effort required to insulate these cells amounts to almost 60 percent of the total cost to society at the budget level considered. At lower overall budget levels, such as the more desirable budget used to generate Figure A-15, no expenditure on building insulation is made by the computer program.
- Implications - A building insulation program should be initiated only if (1) the public is willing to help pay for improvements to their own homes (note that as shown earlier in Table A-9, the city is expected to incur only about 4 percent of the total cost of this countermeasure) and (2) a high degree of expenditure on noise control is desired and possible. If a building insulation program is desired, the noise optimizations for 1980

and 1988 indicate that the following areas deserve initial attention:

1. Residences near Hanover Street (cells B1 and B3)
2. Residences along garbage truck routes - Bayard Street and Roth Avenue (cells R5 and R7)

Reduction of Noise Impacts Due to Expenditures

Figure A-16 shows the relationship between cost expenditure and percent reduction of the noise impact index* for the 1980 Allentown analysis. This relationship clearly indicates that after a certain point, the cost of additional benefits is much higher than before. This point corresponds to a total discounted cost to society of about 1.1 million dollars, equivalent to an expenditure of about $100,000 annually. The associated discounted cost to the city of Allentown (from now to infinity) would be about 0.9 million dollars, or about $82,000 annually. This represents about a 30 percent reduction in the presently anticipated Allentown annual noise control budget, indicating that in the future, a somewhat reduced budget for noise control could be acceptable from the cost effectiveness standpoint.

---

*The Noise Impact Index (NII) is a measure of the impact of noise on a community. A threshold of impact (NII = 0) is defined for each land use type for both day and night noise levels, and a complete impact (NII = 1.0) is defined to be 20 dB above these threshold values.

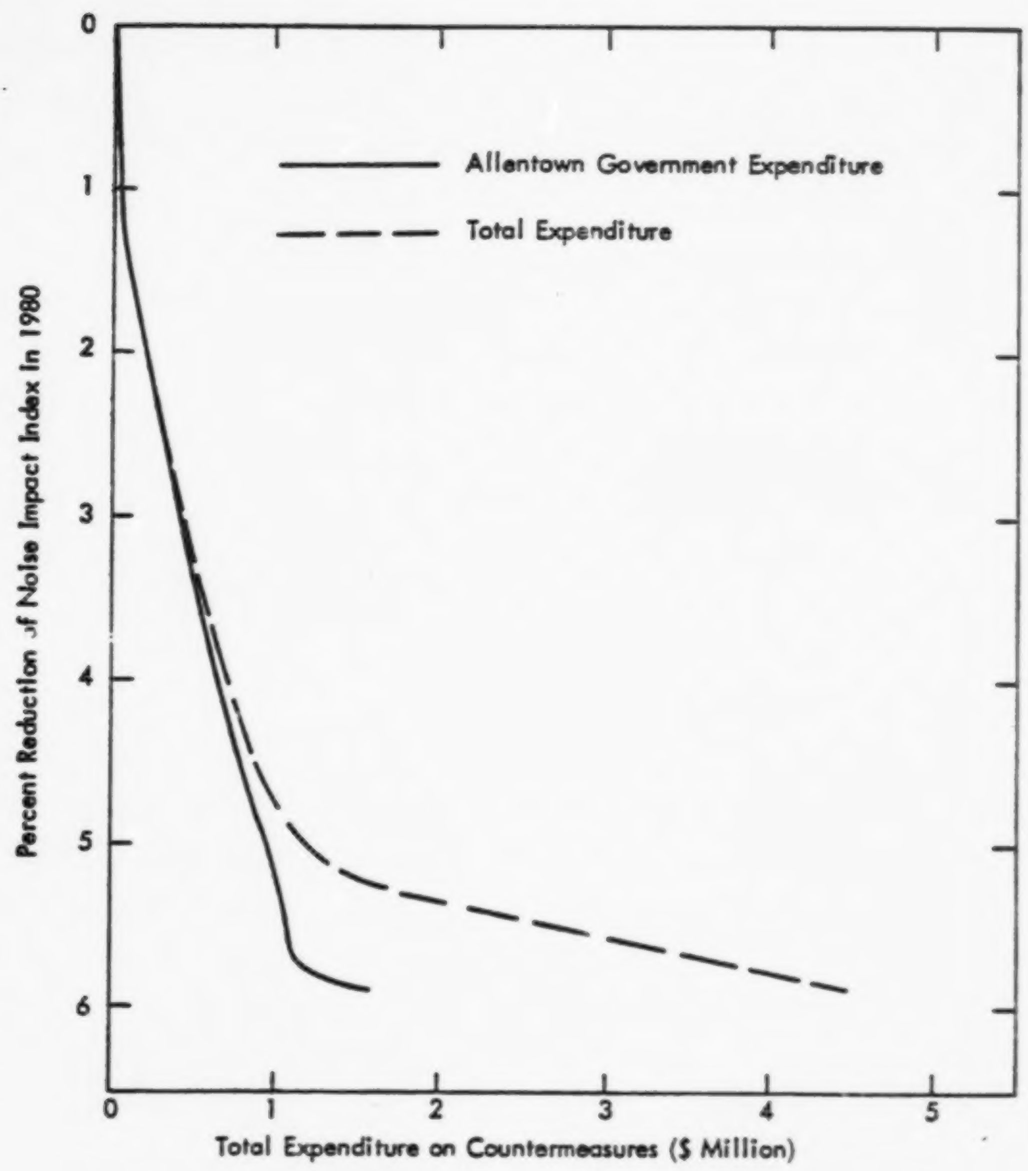


Figure A-16. Relationship Between Total Expenditures on Countermeasures and Reduction of Noise Impact Index in 1980

APPENDIX B

VEHICLE STATISTICS COMPUTER PROGRAM (VESTA)

This appendix describes the operation of VESTA, a computer program for truncating a normal (Gaussian) distribution on the tail of the distribution and redistributing this truncated portion in another Gaussian distribution among the remainder of the distribution.

The program is written in FORTRAN V and was developed and implemented on a UNIVAC 1108 operated by University Computing Company (UCC). The basic concepts underlying the computer program are described in Section B.1, input data preparation and a sample output listing is described in Section B.2, the application of VESTA to four types of abatement measures is described in Section B.3, and a program listing appears in Section B.4.

B.1 Basic Concepts

VESTA provides estimates of the change in the energy-average noise level of a noise source population as a function of time. These changes may be caused by regulations applied to either existing or new noise source populations. All noise level distributions considered by the program are Gaussian. The imposition of a regulation causes the upper tail of the distribution to be truncated at the point corresponding to the regulation level. The portion of the population that is truncated is redistributed into another Gaussian distribution below the regulation level specified by the user.

The Gaussian distribution is a continuous function defined by the following probability density:

$$N(X;\mu,\sigma) = \frac{e^{-\frac{1}{2}\left(\frac{X-\mu}{\sigma}\right)^2}}{\sigma\sqrt{2\pi}}$$

where

μ is the mean value of the distribution,

σ is the standard deviation of the distribution.

The cumulative value of this distribution up to a point, X, represents the fraction of a source population which produces a noise level less than the value specified by X.

A change in the mean energy-average population noise level is brought about by truncating this Gaussian distribution at a specified noise level the value of which is determined by an operational standard or a new vehicle regulation. Truncation transforms population noise sources above a regulation level by redistributing them normally about a lower mean. The overall effect is to lower the population mean and subsequently the fleet average L_{eq}, symbolized by L^{eq}. A pictorial presentation of this truncation and redistributing process is shown in the main text in Figure 3-10 (page 3-55). Notice that not all of the source population above the regulation participates in the redistribution. This is due to the compliance factor which measures the percent of the violating source population above the regulatory limit which can be expected to comply with the regulation after enforcement efforts have been made.

The regulation (or truncation) then separates the vehicle population into three parts. The first part is the portion of the original distribution below the regulation limit. The second part is the fraction of vehicles induced to lower their noise level. The third part is the percentage of those vehicles which are in violation of the regulation and do not lower their noise levels.

After the distribution has been divided into these three parts, they are combined into a new distribution with a new mean and standard deviation which represents the complying population. This new mean and standard deviation can now be used as parameters for a Gaussian distribution. Once the Gaussian distribution has been defined, the L^{eq} can be calculated from the formula

$$L^{eq} = \mu + .115\sigma^2 \quad , \text{dB}$$

where μ and σ are the new mean and standard deviation, respectively, of the combined distribution and the constant 0.115 is (1/2) $(\ln_e 10^{0.1})$.

A distinction needs to be made between the two classes of source populations which are treated in VESTA. These two classes are the existing population and the newly manufactured population.

The existing population is comprised of all noise sources which are already in operation. These could be, for example, all motorcycles in the United States which are on the road. The newly manufactured sources could be those motorcycles just manufactured, and possibly regulated by law, which will begin entering into the existing population.

These two classes of normally distributed noise sources and their interactions are considered in computing the changes in the energy-average source population noise levels as a function of time.

The interaction of the two distributions, existing and newly manufactured, is computed by the following expression for the ensemble energy average noise level after t years.

$$L^{eq}(t) = (1-r)^t \cdot 10^{L_E^{eq}/10} + [1-(1-r)^t] \cdot 10^{L_N^{eq}/10} \quad , \text{dB}$$

where t is the time in years since the new vehicles began entering into the fleet, and
r is the rate at which newly manufactured vehicles replace existing ones.
L_E^{eq} and L_N^{eq} are the fleet energy-average mean levels of the existing and newly manufactured populations, respectively. They are computed from:

$$L_E^{eq} = \mu_E + .115\sigma_E^{\,2} \quad , \text{dB}$$

$$L_N^{eq} = \mu_N + .115\sigma_N^{\,2} \quad , \text{dB}$$

where μ and σ are the means and standard deviations of their respective population distributions.

B.2 Input Data

This section describes the input data to VESTA and the associated code words used to enter this data. There are five such code words; each appear in the first 2, 4, or 5 columns of the card and are the only meaningful characters appearing on that card. Card columns 7 through 79 of a code word card may be used for comments.

1. DIST1
2. REG1
3. DIST2
4. REG2
5. GO

DIST1 - This code word precedes the data corresponding to the distribution of the "existing population." The characters DIST1 appear in card columns 1 through 5.

On the data card that follows, (1) the mean sound level of the source, and (2) the standard deviation of the source distribution, are entered in free format (i.e., separated by a comma).

REG1 - This code word indicates that the following data card will be applied in conjunction with the existing distribution which was either initialized by DIST1 or is the result of the last GO command. The necessary inputs are: (1) the truncation or regulation level in decibels; (2) the mean value in decibels of the redistribution; (3) the standard deviation of the redistribution; and (4) the compliance factor in percent. These data are also input in free format.

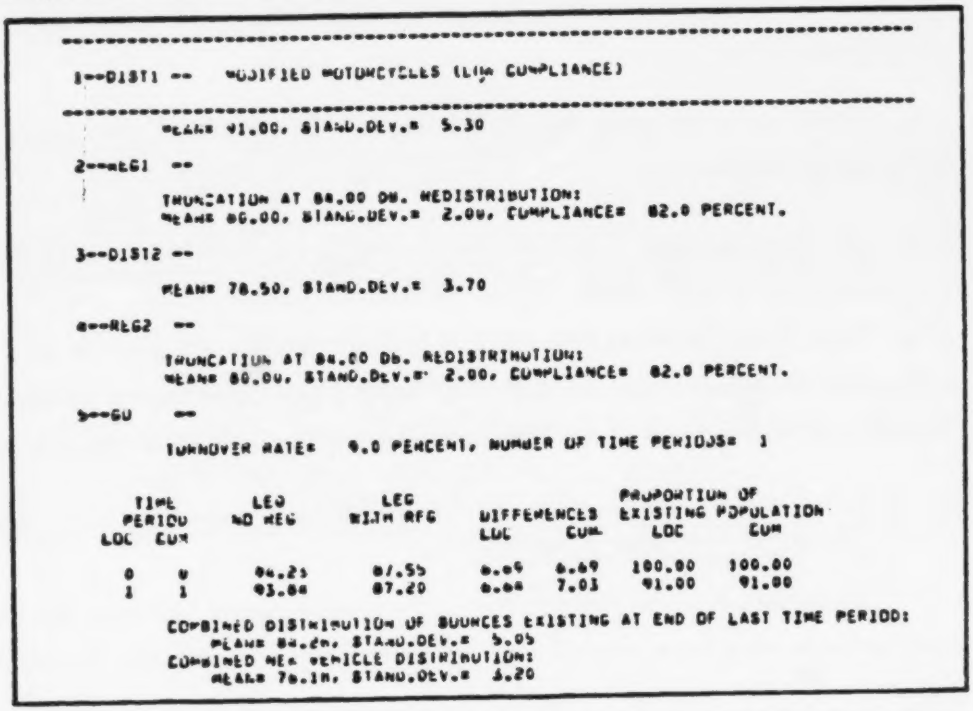
DIST2 - This code word is used to initialize the newly manufactured noise source distribution. It plays the same role with the newly manufactured vehicles and associated inputs as does DIST1 with the existing source population.

REG2 - Same as REG1 except truncation and redistribution are for the distribution which was either initialized by DIST2 or is the result of the last GO command.

GO - This code word indicates the the information following will specify for how long (years) and at what rate the previously defined distributions will interact. Using free format and starting in card column 1, enter the rate at which newly manufactured vehicles will be entered into the fleet (i.e., turnover rate in percent), followed by the number of years you wish to allow the two distributions to interact.

The printout due to each "GO" command gives information in various columns, some labeled "LOC" or "CUM." LOC means "local" which means that values given are local to this GO command. CUM means "cumulative" which means that values given are cumulative from the last DIST1 command.

Figure B-1 illustrates a sample output listing from VESTA. The example shown imposes an 84 dB operational standard on motorcycles. This figure should be examined in conjunction with the above discussion to explain the various input data.



```
-----------------------------------------------------------------------------

1--DIST1 --   MODIFIED MOTORCYCLES (LOW COMPLIANCE)

-----------------------------------------------------------------------------
        MEAN= 91.00, STAND.DEV.=  5.30

2--REG1  --

        TRUNCATION AT 84.00 DB. REDISTRIBUTION:
        MEAN= 80.00, STAND.DEV.=  2.00, COMPLIANCE=  82.0 PERCENT.

3--DIST2 --

        MEAN= 78.50, STAND.DEV.=  3.70

4--REG2  --

        TRUNCATION AT 84.00 DB. REDISTRIBUTION:
        MEAN= 80.00, STAND.DEV.=  2.00, COMPLIANCE=  82.0 PERCENT.

5--GO    --

        TURNOVER RATE=   9.0 PERCENT, NUMBER OF TIME PERIODS=  1


    TIME        LEQ          LEG                         PROPORTION OF
   PERIOD      NO REG      WITH REG      DIFFERENCES   EXISTING POPULATION
  LOC  CUM                                LOC     CUM      LOC      CUM

   0    0       94.25        87.55        6.69    6.69   100.00   100.00
   1    1       93.84        87.20        6.64    7.03    91.00    91.00

        COMBINED DISTRIBUTION OF SOURCES EXISTING AT END OF LAST TIME PERIOD:
            MEAN= 84.28, STAND.DEV.=  5.05
        COMBINED NEW VEHICLE DISTRIBUTION:
            MEAN= 78.18, STAND.DEV.=  3.20
```

Figure B-1. Example Output Listing from VESTA Illustrating an 84 dB Operational Standard for Motorcycles

B.3 VESTA Tax Measures and New Product Regulations

The application of VESTA to four abatement alternatives which reduce noise emissions at the source are considered here. These alternatives are:

1. Property Tax Incentives
2. Business Tax Penalties
3. New Product Regulations
4. New Product Labeling Requirements

Similar methods are used to estimate the noise reductions obtained with each alternative. (1) Each alternative affects new products only – a noise reduction does not occur unless the action causes an old noisy product to be replaced by a newer, quieter one. (2) An estimate of the noise reduction achieved with each alternative in this group requires that information be gathered on the present distribution of noise levels, the fraction of the source population which is modified to produce lower noise levels, and the degree of modification (noise reduction) which occurs. (3) Finally, the effectiveness of each alternative in the group is highly dependent upon the willingness of either the customer or manufacturer to pay for the product modifications desired.

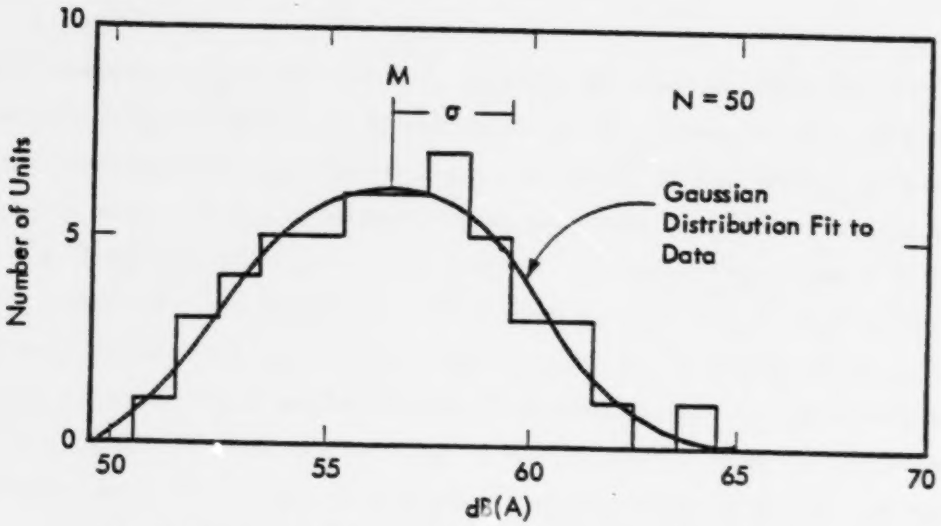
If any one of the above four alternatives is to be considered, then gather the following information:

Item 1 Mean and Standard Deviation of Present Noise Levels Produced by the Noise Source Population Under Typical Operating Conditions

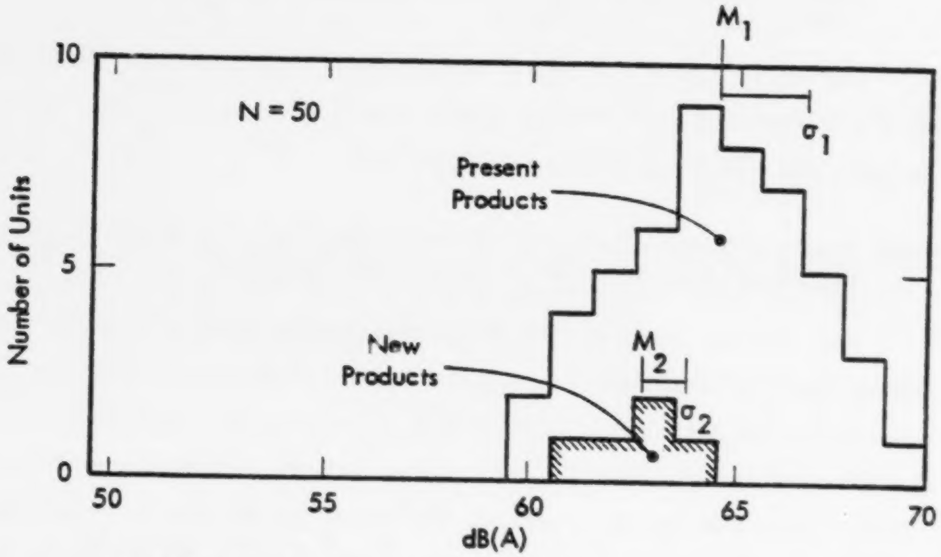
These levels should be measured at a standard distance and stated in terms of L_{eq} over a specified time period. Combine these levels into a histogram and estimate a Gaussian distribution curve to the histogram. An example is shown in Figure B-2(a).

Item 2 Noise Measurement Procedures Which Will Be Used as the Basis for the Tax Measure or New Product Regulation

The manner in which products are to be measured greatly influences the type of modification or repurchase which occurs. A measurement procedure must be established



(a) Noise Levels of Source Population Measured at a Reference Distance Under Typical Operating Conditions, dB (M = Mean, σ = Standard Deviation)



(b) Noise Level of Source Population Measured According to New Product Measurement Procedure, dB (M_1 and σ_1 = Mean and Standard Deviation of Present Products; M_2 and σ_2 = Mean and Standard Deviation of New Products)

Figure B-2. Example of Noise Level Distributions Measured Under (a) Typical Operating Conditions and (b) New Product Measurement Procedure which determines whether or not a given product complies with a regulation or qualifies for a tax break or penalty. This procedure may be the same as that established for existing products (Item 1). In the case of new product regulations, however, the measurement procedure is usually designed to measure the maximum noise levels which a product will generate. The new product regulation then specifies a suitable limit for this maximum noise level. Changes in design required to reduce the maximum level of a given product to a level which complies with the regulation may not cause an equivalent reduction in noise levels measured under typical operating conditions, although this latter reduction is typically the desired goal. This fact must be kept in mind during the development of a new product noise measurement procedure.

Item 3 Mean and Standard Deviation of Present Noise Levels Produced by the Noise Source Population Measured in Terms of the New Product Measurement Procedure (identified in Item 2)

Gather this information only if the measurement procedure identified under Item 2 is different from the procedure used to measure noise levels in Item 1. An example of this distribution is shown in Figure B-2(b).

Item 4 Mean and Standard Deviation of Present New Product Noise Levels Measured According to the New Product Measurement Procedure

To a first approximation, the distribution of noise levels produced by new products coming off the assembly line before any new product regulation, incentive, or penalty is established may be assumed to be the same as the distribution of existing, old products identified in Item 3. If it is known that new products are actually quieter (or noisier) than older products, estimate the form of this new product noise level distribution and find its mean and standard deviation. An example of this distribution is shown in Figure B-2(b).

Item 5 Determine the Cutoff Level for the Incentive, Penalty, or Regulation

Establish a criterion level which will determine which products qualify for tax reimbursement, which products are to be penalized, and/or which products are in violation of a new product noise standard. In addition, if labeling is to be required for new products, it may be desirable to establish a cutoff point so that products exceeding the cutoff are labeled in one way and products which are quieter than the cutoff are labeled in another way. If two or more types of regulations are going to be applied to a given product, use the same cutoff level for each regulation. For instance, an incentive which applies to products emitting less than 70 dB at 15 meters would be complemented by a penalty which applies to all products emitting more than 70 dB at 15 meters.

Item 6 Mean and Standard Deviation of that Portion of New Products Which Are Expected to Be Modified in the Future as a Result of the Regulation or Tax Measure, and the Fraction of New Products Which Are Expected to Be Modified

The distribution of new product noise levels identified in Item 4 will be modified by the abatement measure being proposed to a degree which depends on the strictness of the measure. Estimate the distribution of new product noise levels expected in the future by completing the steps described in Sections 3.4.12, 3.4.13, 3.4.14, or 3.4.15 (of the main text of this manual) depending on which type of measure is being considered.

Once Items 3 through 6 have been gathered, the reduction of noise levels measured according to the new product measurement procedure can be estimated using the VESTA computer program for each of the four new product abatement measures: tax incentive, tax penalty, new product regulation, and labeling. The desired output is given under the heading "DIFFERENCES," indicating the difference between the population-averaged noise level, L^{eq}, with and without the abatement measure under consideration. Difference values are provided over a range of years from the time the measure is implemented. Identify the appropriate year based on the target year selected in Section 3.2 of the main text, and note the corresponding L^{eq} difference value. This difference may be assumed to represent the reduction in the noise level of the source in the community, as long as the new product measurement procedure developed under Item 2 above is an indicative measure of typical operating conditions. If it is not (as is often the case), a further item of information needs to be gathered before the noise reduction evaluation is complete.

Item 7 Relationship Between Noise Levels Produced Under the New Product Measurement Procedure and Noise Levels Produced Under Typical Operating Conditions

In many cases, a new product measurement procedure is designed to elicit maximum noise emissions under an operating mode rarely encountered in the real world. A test mode under maximum throttle is an example. However, usually the test mode is representative of some aspect of production operation. For instance, maximum throttle is representative of the acceleration mode of a vehicle. Estimate the fraction of time engaged in this mode. As a first approximation, the reduction of the average noise level produced under the acceleration mode may be assumed to be equal to the L^{eq} difference found by the VESTA program, although this is often an overestimate. Other modes may be unaffected by the reduction in noise produced under the test conditions. For instance, noise levels produced under idling conditions are not affected much by acceleration noise level reductions. Estimate the fraction of time typically spent in these unaffected modes. Finally, the remaining modes of operation, affected to an intermediate degree, must be considered. Estimate the reductions in average levels for these modes, noting that the noise reductions in these modes will be less than in those that are similar to the test procedure, but will be greater than zero. In the absence of any other information, assume the noise reduction varies linearly with engine rpm from zero at engine idle speed to the maximum value at the engine speed for maximum throttle.

After these estimates have been made, estimate the total average noise reduction for the noise source in question from the following equation:

$$\Delta L_{eq} = 10 \log \left(\sum_{i=1}^{m} t_i \cdot 10^{(L_i - \Delta L_i)/10} \right) \text{, dB}$$

where

m is the number of operating modes,
t_i is the fraction of time spent in the i^{th} mode,
L_i is the original noise level of the i^{th} mode, and
ΔL_i is the noise reduction of the i^{th} mode obtained with the abatement measure.

B.4 VESTA Program Listing

```
C THIS PROGRAM ALLOWS THE INVESTIGATION OF THE CHANGE OF EQUIVALENT
C POPULATION NOISE LEVEL AS A FUNCTION OF TIME AND REGULATIONS APPLIED
C TO AN 'EXISTING' AND A 'NEW' POPULATION OF NOISE SOURCES. ALL NOISE
C LEVEL DISTRIBUTIONS ARE NORMAL. REGULATIONS CAUSE THE UPPER TAIL OF
C THE DISTRIBUTION TO BE TRUNCATED. THE PORTION OF THE POPULATION THAT IS
C TRUNCATED IS ALLOWED TO BE REDISTRIBUTED ACCORDING TO ANOTHER NORMAL
C DISTRIBUTION AS SPECIFIED BY THE USER.
C
      IMPLICIT LOGICAL (L)
      DIMENSION T1H(2),YT1H(2),T2H(2),YT2H(2),ZT1H(2),ZT2H(2),A(6),
     1ICODEW(5),TITLE(12)
      DATA ICODEW/'REG1  ','REG2  ','GO    ','DIST1 ','DIST2 '/
C
C ASSIGNMENT OF INITIAL AND DEFAULT VALUES
      T1H(1)=0.
      T1H(2)=.1
      XT1=1000.
      YT1H(1)=0.
      YT1H(2)=.1
      T2H(1)=0.
      T2H(2)=.1
      XT2=1000.
      YT2H(1)=0.
      YT2H(2)=.1
      L1=.FALSE.
      L2=.FALSE.
      LBASE=.TRUE.
      K=0
C
C READS A CODEWORD (OR COMMAND)
   21 READ(5,14,END=3)IO,TITLE
   14 FORMAT(A6,12A6)
      K=K+1
C
      DO 15 I=1,5
      N=I
      IF(IO.EQ.ICODEW(I))GO TO 16
   15 CONTINUE
C
      WRITE(6,17)IO
   17 FORMAT('0***ERROR: ',A6,' IS AN UNRECOGNIZABLE CODEWORD!')
      GOTO 3
C
16    IF(N.EQ.4)WRITE(6,52)
52    FORMAT('1',79('-'))
      WRITE(6,22)K,ICODEW(N),TITLE
   22 FORMAT(/I3,'--',A6,'--',2X,12A6/)
      IF(N.EQ.4)WRITE(6,53)
53    FORMAT(' ',79('-'))
C
C BRANCHES ACCORDING TO SELECTED CODEWORD
      GO TO(18,19,20,31,32),N
C
C READS A REGULATION 1: AFFECTING THE 'EXISTING' SOURCES
   18 READ(5,30,END=4)XT1,YT1H,L1
   30 FORMAT()
      WRITE(6,36)XT1,YT1H,L1
      IF(.NOT.L1)GOTO 39
```

```
36    FORMAT(T11,'TRUNCATION AT',F6.2,' DB. REDISTRIBUTION:'/
     +T11,'MEAN=',F6.2,', STAND.DEV.=',F6.2,', COMPLIANCE=',F6.1,
     +' PERCENT.')
      C1=C1/100.
      GO TO 21
C
C READS AN 'EXISTING' SOURCES DISTRIBUTION (1)
31    READ(5,30,END=4)T1H
      WRITE(6,33)T1H
33    FORMAT(T11,'MEAN=',F6.2,', STAND.DEV.=',F5.2)
      L1=.TRUE.
      LBASE=.TRUE.
      GOTO 21
C
C READS A 'NEW' SOURCES DISTRIBUTION (2)
32    READ(5,30,END=4)T2H
      WRITE(6,33)T2H
      L2=.TRUE.
      GOTO 21
C
34    WRITE(6,35)
35    FORMAT('0** ERROR: GO MUST BE PRECEDED BY ATLEAST ONE'
     +/T11,'DIST1 OR DIST2 COMMAND.')
      GOTO 3
C
C READS A REGULATION: AFFECTING THE 'NEW' SOURCES
   19 READ(5,30,END=4)    XT2,YT2H,C2
      WRITE(6,36)    XT2,YT2H,C2
      C2=C2/100.
      IF(.NOT.L2)GOTO 40
      GO TO 21
39    WRITE(6,41)
41    FORMAT('0** ERROR: REG1 MUST BE PRECEDED BY DIST1.')
      GOTO 3
40    WRITE(6,42)
42    FORMAT('0** ERROR: REG2 MUST BE PRECEDED BY DIST2.')
      GOTO 3
C
C COMES HERE DUE TO 'GO' CODEWORD. READS TURNOVER RATE AND NUMBER OF
C     TIME PERIODS.
   20 READ(5,30,END=4)G,N
      WRITE(6,37)G,N
37    FORMAT(T11,'TURNOVER RATE=',F6.1,' PERCENT, NUMBER OF TIME PERIODS
     +=',I3)
      G=G/100.
      IF(.NOT.(L1.OR.L2))GOTO 34
      WRITE(6,24)
   24 FORMAT(///X,'TIME',T19,'LEQ',T31,'LEQ',T53,
     +'PROPORTION OF'/T7,'PERIOD',T17,'NO REG',T28,'WITH REG',
     +T40,'DIFFERENCES',T53,'EXISTING POPULATION'/
     +'     LOC  CUM',T40,'LOC',T48,'CUM',T56,'LOC',T65,'CUM'/)
C
C E1 =  NOISE ENERGY FROM EXISTING SOURCES DISTRIBUTION
C E2 =  NOISE ENERGY FROM FUTURE NEW SOURCES DISTRIBUTION
C E1T = NOISE ENERGY CONTRIBUTION FROM THE TRUNCATED PORTION OF THE
C          EXISTING SOURCES
C E2T = NOISE ENERGY FROM THE TRUNCATED PORTION OF THE FUTURE NEW SOURCES.
C E1R = NOISE ENERGY FROM EXISTING SOURCES AFTER REGULATION: CONSISTS OF
C          THREE CONTRIBUTIONS: PORTION LEFT AFTER TRUNCATION, NONCOMPLYING
C          PORTION ABOVE TRUNCATION POINT, REDISTRIBUTED COMPLYING PORTION.
```

```
C E2R = NOISE ENERGY FROM FUTURE NEW SOURCES AFTER REGULATION.
C
      E1=ESD(T1M,-1.,0)
      E2=ESD(T2M,-1.,0)
      IF(XT1.LT.1000.)GO TO 10
      E1T=E1
      P1=1.
      E1RN=.0
      GO TO 11
C
   10 E1T=ESD(T1M,XT1,P1)
      E1RN=ESD(YT1M,XT1,0)
C
   11 IF(XT2.LT.1000.)GO TO 12
      E2T=E2
      P2=1.
      E2RN=.0
      GO TO 13
C
   12 E2T=ESD(T2M,XT2,P2)
      E2RN=ESD(YT2M,XT2,0)
C
   13 E1R=P1*E1T+(1.-P1)* C1*E1RN+(1.-C1)*(E1-P1*E1T)
      E2R=P2*E2T+(1.-P2)* C2*E2RN+(1.-C2)*(E2-P2*E2T)
C
C CALCULATE POPULATION EQUIVALENT LEVELS WITH AND WITHOUT REGULATIONS
      S=1.-G
      IF(.NOT.LBASE)GOTO 51
      WC=1.
      IC=0
51    W=1.
      WP=WC
C
      DO 1 I=0,N,1
      IP=IC+I
      RLEQ=10.*ALOG10(W*E1+(1.-W)*E2)
      IF(.NOT.LBASE) GO TO 50
      BASELQ=RLEQ
      LBASE=.FALSE.
   50 RLEQR=10.*ALOG10(W*E1R+(1.-W)*E2R)
      DELLEQ=RLEQ-RLEQR
      TDELQ=BASELQ-RLEQR
      WRITE(6,23)I,IP,RLEQ,RLEQR,DELLEQ,TDELQ,W ,WP
23    FORMAT(I7,I5,2F11.2,F9.2,F7.2,2P2F9.2)
      W=W*S
1     WP=WC*W
C
      WC=WC*W/S
      IC=IC+N
      IF(XT1.LT.1000.)GO TO 26
      ZT1M(1)=T1M(1)
      ZT1M(2)=T1M(2)
      GO TO 27
C
   26 A(1)=C1
      A(2)=YT1M(1)
      A(3)=YT1M(2)
      A(4)=T1M(1)
      A(5)=T1M(2)
      A(6)=XT1
```

```
C
      CALL MUSIG(ZT1M(1),ZT1M(2),A)
C
   27 IF(XT2.LT.1000.) GO TO 28
      ZT2M(1)=T2M(1)
      ZT2M(2)=T2M(2)
      GO TO 29
C
   28 A(1)=C2
      A(2)=YT2M(1)
      A(3)=YT2M(2)
      A(4)=T2M(1)
      A(5)=T2M(2)
      A(6)=XT2
C
      CALL MUSIG(ZT2M(1),ZT2M(2),A)
C
   29 T1M(1)=A*ZT1M(1)+(1.-A)*ZT2M(1)
      T1M(2)=A*(ZT1M(2)*ZT1M(2)+ZT1M(1)*ZT1M(1))
      T1M(2)=T1M(2)+(1.-A)*(ZT2M(1)*ZT2M(1)+ZT2M(2)*ZT2M(2))-T1M(1)**2
      T1M(2)=SQRT(T1M(2))
C
      XT1=1000.
      YT1M(1)=0.
      YT1M(2)=.1
      XT2=1000.
      YT2M(1)=0.
      YT2M(2)=.1
      T2M(1)=ZT2M(1)
      T2M(2)=ZT2M(2)
C
      U2=10.*ALOG10(ESD(T2M,-1.,A))
      U1=10.*ALOG10(ESD(T1M,-1.,A))
C
      T1M(1)=T1M(1)-U1+HLEQR
      T2M(2)=T2M(2)-U2+10.*ALOG10(E2M)
      LT=.TRUE.
C
      WRITE(6,36)T1M,T2M
36    FORMAT(/T11,'COMBINED DISTRIBUTION OF SOURCES EXISTING AT END OF L
     +AST TIME PERIOD:'/T15,'MEAN=',F6.2,', STAND.DEV.=',F6.2/
     +T11,'COMBINED NEW VEHICLE DISTRIBUTION:'/T15,'MEAN=',F6.2,
     +', STAND.DEV.=',F6.2)
      GO TO 21
C
    3 CALL EXIT
C
    4 WRITE(6,25)
   25 FORMAT('0**ERROR: UNEXPECTED EOF ON UNIT 5.')
      GO TO 3
C
C
C
C
      FUNCTION ESD(TM,XT,P)
      DIMENSION TM(2)
      DATA HLP2/0.2302585/
C
      IF(XT.LT.0.)GO TO 4
      P=RNORM((XT-TM(1))/TM(2))
    4 ESD=10.**((TH(1)+TH(2)*TH(2)*RLN2/2.)/10.)
      IF(XT.LT.0.)RETURN
      ESD=ESD*RNORM((XT-TH(1)-TH(2)*TH(2)*RLN2)/TH(2))/P
C
      RETURN
C
C
C
C
      SUBROUTINE MUSIG(MU,SIG,S)
      REAL MU,SIG,S(6),AR,RNORM,PI,C2,LEN1,LEN2,REV,FN,E,FAC,U
      DATA PI/3.14159/
C
      AR=(S(6)-S(4))/S(5)
      E=EXP(-.5*AR**2)
      C2=1.0-S(1)
      FN=1.0-RNORM(AR)
      FAC=S(1)*S(5)/SQRT(2.0*PI)
      U=1.-FN+C2*FN
      MU=FN*S(1)*S(2)+S(4)*U-FAC*E
      LEN1=S(2)**2+S(3)**2
      LEN2=S(4)**2+S(5)**2
      REV=S(6)+S(4)
      SIG=LEN1*S(1)*FN+LEN2*U-FAC*REV*E-MU**2
      SIG=SQRT(SIG)
C
      RETURN
      END
```

```
000001           FUNCTION RNORM(X)
000002           DIMENSION A(7)
000003           DATA(A(I),I=1,7)/.4306383E-4,.2765672E-3,.1520143E-3,.92705272E-2,
000004          1.422820123E-1,.7052307840E-1,1.0/
000005     C-----------------------------------------------------------------------
000006     C     TO  COMPUTE A RATIONAL FUNCTION  APPROXIMATION TO  THE NORMAL
000007     C     DISTRIBUTION
000008     C-----------------------------------------------------------------------
000009           Y=ABS(X)/1.41421356
000010           RNORM=0.0
000011           DO 1 I=1,7
000012           RNORM=RNORM*Y+A(I)
000013           CALL OVERFL(INDCT)
000014           IF(INDCT.EQ.1) GO TO 3
000015         1 CONTINUE
000016           RNORM=.5*(((((  1.0/RNORM)**2)**2)**2)**2)
000017         2 IF(X.GT.0.0) RNORM=1.0-RNORM
000018           RETURN
000019         3 RNORM=0.0
000020           GO TO 2
000021           END
```

Attention is called to line 13 above which calls for OVERFL(INDCT). This is a routine, defined as follows, to test and reset arithmetic overflow indicator.

CALL OVERFL (J)

J (integer) = 1 if overflow indicator is on.
= 2 if overflow indicator off.

The arithmetic overflow indicator is set on or off by fixed point adds and subtracts and may be tested and rest with this call. Reference: University Computing Company, "V-1108 Executive System," UCC Publication 3025, updated periodically. If such a routine is not available in other computing systems, the user of VESTA should write a subroutine OVERFL which simply tests whether the value of RNORM (line 12 of FUNCTION RNORM) has come close to the largest real number that computer allows. Alternatvely, the user may simply elect to delete lines 13 and 14 from this subroutine if it is not expected that numerical range problems will occur.